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ESTABLISHMENT AND DISCONTINUANCE CRITERIA FOR PRECISION
LANDING SYSTEMS(U) FEDERAL AVIATION ADMINISTRATION
WASHINGTON DC OFFICE OF AVIATION POLICY AND PLANS

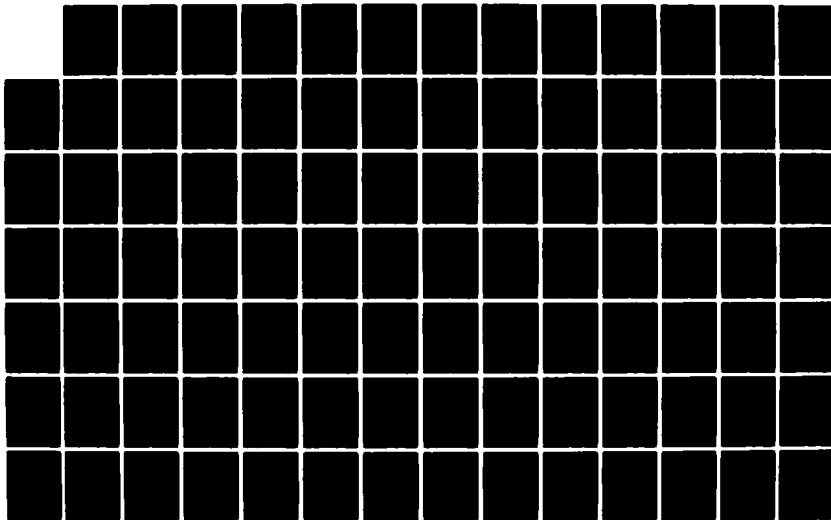
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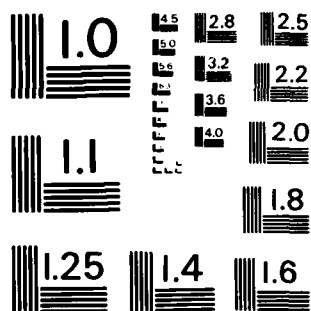
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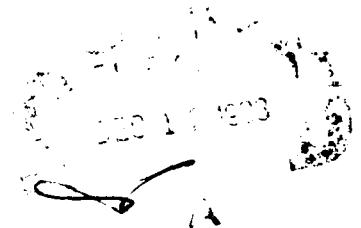
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Establishment and Discontinuance Criteria for Precision Landing Systems

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EXECUTIVE SUMMARY

This report describes the development of establishment criteria for the standard Microwave Landing System (MLS) with approach lights. The criteria were empirically derived from a benefit/cost analysis. The key elements of the criteria are expressed as a function of (a) annual instrument approaches (AIA's) by user category, (b) non-precision approach minima on the candidate runway, and (c) the probability of IFR weather at the airport. These criteria apply only to runways that are being considered for a precision approach aid for the first time.

Benefits of an MLS vary widely depending on the proportionate use of the MLS runway, the distribution of instrument weather at the airport, aircraft operating costs, average number of passengers, and other factors. The MLS candidate runways, after first being qualified by regional offices on the basis of establishment criteria published in Airway Planning Standard Number One (APS-1), will then be evaluated by a benefit/cost analysis at FAA headquarters. This analysis will use data furnished by the regions with their responses to the annual Call for Estimates when the data are available. Otherwise, national averages developed by the Office of Aviation Policy and Plans will be used.

It is estimated that through 1985, the criteria will identify 218 new MLS candidates. Through 1995 the number of potential candidates is expected to reach 324. In addition to these systems, there will be approximately 768 systems in the ILS inventory that will each be replaced by an MLS in accordance with guidelines developed in FAA's Microwave Landing System Transition Plan. This ILS/MLS replacement policy together with the application of MLS criteria contained herein represents 1092 (768 + 324) or approximately 1100 systems by 1995.

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1. Introduction

Good management of proposed capital investments requires analysis and comparison of benefits and costs. FAA evaluates its investments in navigation aids, communication aids, and control towers for the National Airspace System, by applying standard establishment and discontinuance "criteria." FAA's criteria are summarized in an FAA Order, 7031.2B, called "Airway Planning Standard Number One - Terminal Air Navigation Facilities and Air Traffic Control Services" (Reference 1). For inexpensive devices, the criteria are simple traffic activity thresholds: an airport with 50,000 operations per year qualifies for an ATIS (Automatic Terminal Information Service), for example. Larger facilities, such as precision landing systems, have more complicated criteria, which require economic analysis of benefits and costs.

This report presents the economic analysis of costs and benefits of the Microwave Landing System (MLS) with a Medium Intensity Approach Light System with Runway Alignment Indicator Lights (MALSR), and the criteria for establishment and discontinuance based on this analysis. Other reports treat economic criteria for other elements of the National Airspace System. A more general discussion of benefit-cost analysis may be found in "Economic Analysis of Investment and Regulatory Decisions - A Guide" (Reference 2).

A. Kinds of Benefits and Costs

FAA's economic criteria are based on five kinds of benefits and two kinds of costs. Precision landing systems yield several of these:

- o Safety benefits stem from the assumption that most capital investments will reduce accidents. At airports with precision landing systems, runway alignment and hard landing accidents are less frequent. Historical statistics at locations with and without precision approach capabilities may be used to calculate differential accident rates as a function of forecast activity at the airport. These rates are used to predict expected accidents, fatalities, injuries and property losses.
- o Aircraft operating costs are avoided and passengers' time is saved when flight paths are shortened. The MLS allows a shorter approach path than either the ILS, or a non-precision approach. Like safety, these benefits increase with activity.
- o Benefits for avoided flight disruptions are realized when an investment results in opening the airport to traffic when weather would otherwise have closed it. Benefits are calculated from the avoided cost of diverting flights to another airport. Avoided flight disruptions are a key source of landing system benefits.

- o Productivity benefits result when an investment reduces required manpower. Precision landing systems, do not, in themselves, yield direct productivity benefits (although they may improve on the maintainability of an older, less reliable system).
- o Other benefits can be qualitatively described, but cannot be quantified.
- o Investment costs include the capital expenditure for the device, and whatever site improvements must be made to accommodate it. Costs are estimated for a particular site, so that airports with fewer problems will have lower costs. In a discontinuance benefit cost analysis, one-time costs of discontinuing operation are tallied.
- o Operations and maintenance costs are estimated for both labor and materials costs.

B. "Critical" Values and Operations Forecasts

Standard unit values are assigned to fatalities, injuries, and time to provide a common basis for comparing costs and benefits. Particular values for these as well as aircraft repair, replacement, and operating costs, were recommended by a 1981 report (Reference 3) and are now a part of Airway Planning Standard Number One. Critical values should be updated annually, insuring that the criteria reflect differences in the inflation rates of these values and costs.

Aviation activity projected in FAA's annual Terminal Area Forecasts is used to estimate most benefits. Benefit and cost values are computed for each of 15 future years, discounted to present value with the 10% rate directed by the Office of Management and Budget, and summed to determine present value of costs and benefits over an expected 15 year life. The useful life of the investment may be longer than 15 years, but assuming a 15 year life results in a more conservative investment strategy, and provides better protection against obsolescence due to technological or policy changes.

C. How Criteria are Applied

The benefit/cost criteria are applied in two phases, with the first phase being an abbreviated version of the second. The Phase I criteria are used by the FAA regional offices to initially screen locations for budget request submissions. Phase II is the complete benefit/cost analysis described in this report and supported by a computer program managed by FAA's Office of Aviation Policy and Plans.

Establishment criteria are used to evaluate investments at particular locations prior to Facilities and Equipment (F&E) budget submissions, or reprogrammings. Locations are considered "candidates" if they meet the Phase I criteria for three consecutive annual counts. The Phase II benefit/cost analysis is used to evaluate candidates before they are submitted as budget requests. Meeting the economic criteria is usually a

necessary condition for including a site in the budget. But the number of qualifying sites is usually larger than overall budget constraints will allow to be implemented, so some sites may not be funded, even if economically justified. The converse is also true: locations may be excepted from meeting the economic criteria because of other factors. For landing systems, one of these exceptions is the landing system's potential to relocate pilot training activity from a nearby congested hub.

Installations may be discontinued if the benefits fall below annual operation and maintenance costs, adjusted for any one-time shutdown costs. This can happen if activity levels drop, or reanalysis of benefits suggests that investments do not provide the same degree of benefit as previously believed.

D. Changes from Previous Criteria

This report, and the changes to APS-1 that will result from it, represents a revision of FAA report ASP-75-1, "Establishment Criteria for Category I Instrument Landing Systems" (Reference 4). The change reflects updating of critical values, and provision for utilizing site specific activity forecasts.

E. Organization of This Report

Phase II benefit/cost criteria and simple Phase I criteria are presented in Chapter II. Complete details for the cost calculations are given in Chapter III, and for the benefit calculations in Chapter IV. The results of applying these criteria are presented in Chapter V. Chapter VI discusses development of the simple Phase I criteria. The sensitivity of the criteria results to several key assumptions and inputs is discussed in Chapter VII. A manual method for calculating the Phase II benefit/cost ratio is presented in Chapter VIII. As a practical matter a computer program will be used to calculate these ratios.

II. Precision Landing System Criteria

The criteria developed in this document pertain primarily to MLS since there are no plans to budget for new ILS establishments. The MLS establishment criteria apply to those runways that are new candidates for a precision landing aid. ILS discontinuance criteria have been revised to reflect more current costs and benefit values and are included in this report as Appendix G.

A. Benefit/Cost Criteria (Phase II)

The Phase II criteria are a comparison of the present value of the quantitative benefits of installing a precision landing aid, with the present value of the establishment costs for the aid. A useful life of fifteen years is the standard that is applied to navigational aids. The ratio of life cycle benefits over life cycle costs is calculated to determine whether an airport or runway qualifies as a candidate for a precision landing aid. Life cycle benefits and costs are derived by discounting future costs and benefits to the present at a compound rate (10 percent is used by OAG Directive) and summing. The benefit/cost criteria are met when the ratio of benefits to costs is 1.0 or greater. If this ratio is less than 1.0, costs exceed benefits and, technically, the investment has failed the criteria test. However, where benefit/cost ratios are not significantly higher or lower than 1.0, i.e., .9 and 1.1, these are marginal cases, and additional screening involving considerations other than economics should be made. There is a significant amount of estimating that occurs in cost/benefit analysis that make it difficult to always obtain results that can be viewed as conclusive. A small margin for error must be taken into account.

1. Establishment Criteria: A runway where scheduled turbojet operations are conducted on a sustained basis and are expected to continue without long periods of interruption is a candidate for MLS. Any other runway or heliport not currently equipped with an operating precision approach system is validated as a candidate for MLS when the life cycle benefits of the system equals or exceeds the life cycle costs.

$$B/C \geq 1.00$$

2. Discontinuance Criteria: At a runway where scheduled turbojet operations are conducted the ILS shall not be decommissioned. All other runways are candidates for decommissioning of precision landing equipment when the operation and maintenance costs of providing the service exceed the benefits derived. To make this determination, 15-year discounted O&M costs (not investment costs) are compared with benefits over the same time period.

B. Summary of Phase I Criteria

Phase I criteria are a set of generalized criteria designed to identify potential candidates for precision landing system establishment and discontinuance. Unlike Phase II benefit/cost criteria, they are easily applied with available data and without the aid of a computer. Under Phase I, a ratio value is computed for each aircraft class by dividing

the number of instrument approaches at the runway for that aircraft class by the number of instrument approaches which would qualify a runway for a precision landing system, if it had approaches in only that class. The ratios for all aircraft classes are summed to obtain the Phase I Ratio Sum. These criteria will apply to those runways not meeting the turbojet operations criteria.

Establishment

Normally, establishment candidacy requires a ratio sum of at least 1.0. Candidacy is validated in Phase II. Although the two phases may not always agree, Phase I criteria are published in Airway Planning Standard One because they provide a useful screening tool as well as easily understood, approximate, measures of activity levels which qualify locations for microwave landing system establishment or discontinuance. If the two phases yield different results, the Phase II benefit/cost criteria should prevail.

Discontinuance

Under Phase I criteria a runway is a candidate for decommissioning of a microwave landing system when the instrument approach activity falls below 30% of the qualifying level, i.e., Phase I sum of ratio values of less than 0.30. The decommissioning of a microwave landing system must be justified by a benefit/cost study, along with a review and assessment of operational and environmental factors pertinent to the affected locality or localities.

C. Phase I Application

To determine whether an airport meets the Phase I or annual instrument approach (AIA) criterion:

1. Determine the least instrument minimum currently authorized for the largest aircraft using the candidate runway.
2. Reference table 2-1 to set of the required numbers of AIA's on the candidate runway for each user category for the minimums referenced in the preceding step.
3. Compute the number of recorded AIA's on the candidate runway for each user category as follows:
 - a. Determine the AIA's from an on-site survey or,
 - b. Multiply the number of total AIA's by the percentage of airport AIA's on the candidate runway, (if site specific data are unavailable, apply 75% to first runway, 25% to second runway. For the third or subsequent runways a site survey of projected 100 runway usage will be required.) or,
 - c. Calculate AIA's using the Systems Control Inc. (SCI) model developed in Appendix C.

4. Enter recorded and required AIA's for the candidate runway as indicated below. The contributions of each category toward meeting the criteria are summed. A runway with a total ratio of 1.0 or more meets the AIA criteria.

User Category

Air Carrier $\frac{\text{Recorded AIA's}}{\text{Required AIA's}} = x.xx$

Air Taxi $\frac{\text{Recorded AIA's}}{\text{Required AIA's}} = x.xx$

General Aviation $\frac{\text{Recorded AIA's}}{\text{Required AIA's}} = x.xx$

Military $\frac{\text{Recorded AIA's}}{\text{Required AIA's}} = x.xx$

Total Ratio $x.xx$

Table 2-1

MLS Qualifying (Required) AIA Count for Stated Minimums

| <u>User Category</u> | 300-3/4 | 400-3/4 | 400-1 | 500-1 | 600-1 | 800-1 |
|----------------------|---------|---------|-------|-------|-------|-------|
| Air Carrier | | | | | | |
| Hub | 500 | 250 | 200 | 150 | 100 | 50 |
| Non-Hub | 900 | 500 | 400 | 300 | 200 | 100 |
| Air Taxi | 500 | 475 | 450 | 400 | 350 | 300 |
| General Aviation | 2700 | 2300 | 2000 | 1700 | 1400 | 900 |
| Military | 1100 | 1000 | 900 | 800 | 650 | 450 |

A worksheet is presented in Figure 2-1 to facilitate data requirements and computations for Phase I criteria application.

Figure 2-1

Worksheet for Application of MLS
Phase I Criteria

Location _____ Runway _____
 Airport _____ Hub (Yes/No) _____
 IFR Minima: Non Precision _____ MLS _____
 Estimated IFR Use of Candidate Runway (%) _____

AIA's on Candidate MLS Runway. (Current Year):

$$\text{AIA's} \times \text{IFR Runway Use Factor (\%)} = \text{AIA's on Candidate Rwy}$$

Air Carrier
 Air Taxi
 General Aviation
 Military

Proportion of Criteria Satisfied:

$$\frac{\text{Recorded AIA's}}{\text{Qualifying AIA's}} = \text{Ratio}$$

Air Carrier
 Air Taxi
 General Aviation
 Military

Total _____

III. MLS Costs

There are two categories of costs associated with precision approach aids that are relevant to this analysis:

- o Investment costs: the one time costs of facilities and equipment purchase, and operational start-up.
- o Annual costs: operation and maintenance costs

A. Initial Costs

1. Investment Costs

The primary investment costs of establishing a precision landing aid include the ground equipment, installation costs and all non-recurring logistics costs. Standard MLS ground equipment consists of:

1. azimuth antenna and electronics
2. elevation antenna and electronics
3. field monitors
4. remote maintenance monitors
5. remote control and status panels
6. distance measuring equipment
7. approach lights (Medium Intensity Approach Light System with Runway Alignment Indicator Lights (MALSR))

Installation costs for ground equipment include costs for site preparation and construction, actual equipment installation and check-out, and flight check and certification.

Nonrecurring logistic support costs include costs for providing the initial spares and support equipment required to stock the pipelines and all maintenance facilities, for introducing new coded supply items in the user inventory, for training maintenance personnel to work on the MLS equipment, for providing the necessary technical manuals and other documentation, and for transporting the system to its initial destination. Whenever a location must take action in order to meet clear-zone requirements, the costs involved should be counted as a nonrecurring logistics cost.

2. Annual Costs

The annual costs are the recurring logistics support costs or the costs associated with operating and maintaining the equipment over its active life. The major contributors to recurring logistics support costs for MLS are the costs associated with spares and on- and off-site maintenance.

Other recurring logistic support costs include those for operating the MLS sites and the maintenance support equipment when used, training additional MLS maintenance personnel as a result of repair personnel turnover, and keeping the technical documentation current over the life of the system.

Typical MLS system costs are summarized in Table 3-1. Since costs can vary somewhat from site to site, the criteria have been designed so that site specific values may be used for some or all of the costs listed in Table 3-1.

TABLE 3-1
MICROWAVE LANDING SYSTEM ESTABLISHMENT COSTS
(1981 \$000 Dollars)

| <u>Cost Item</u> | <u>MLS</u> | <u>MALSR</u> | <u>TOTAL</u> |
|-------------------------|--------------------|------------------------|--------------------|
| Investment (000) | | | |
| Acquisition | \$462 | \$ 72 | \$534 |
| Installation | 185 | 135 | 320 |
| Non Recurring Logistics | <u>82</u> \$729 | <u> </u> \$207 | <u>82</u> \$936 |
| Annual O&M | \$ 40 | \$ 16 | \$ 56 |

Source: Updated Acquisition Paper for MLS (December 18, 1981), APM-410

B. Present Value Costs

As stated earlier precision landing system benefits are compared with precision landing system costs over a fifteen year time frame, by comparing their present values. It is reasonable to assume that investment costs all occur at the beginning of the time frame, so that their present value equals actual costs. Since constant (1981) dollars are used throughout the analysis, the annual costs will be the same for each year in the time frame. The present value of a stream of constant values is simply a cumulative discount factor times the constant value. In this case the number for 15 years at the ten percent discount rate (mid-year discounting) prescribed by the Office of Management and Budget is 7.976.

Assuming that

$COSTA = \text{Annual Costs}$

$COSTI = \text{Investment Costs}$

the present value of precision landing system costs, PV_C , is given by

$$PV_C = (7.976 \times COSTA) + COSTI$$

Life-Cycle costs for MLS thus become

| <u>COST ITEM</u> | <u>COST (000)</u> | <u>CUMULATIVE DISCOUNT FACTOR</u> | <u>DISCOUNTED 15-YEAR COSTS (000)</u> |
|------------------|-------------------|---------------------------------------|---|
| Investment | \$ 936 | 1.000 | \$ 936 |
| Annual O&M | 56 | 7.976 | <u>447</u> |
| TOTAL | | | \$1383 |

IV. Precision Landing System Benefits

The relevant benefits in this analysis are those benefits that are expected to derive from having precision landing capability as opposed to not having it. A precision landing system provides lateral, vertical, and sometimes distance guidance information (MLS) for landing to those aircraft equipped with the necessary electronic hardware. Through its ability to reduce non-precision approach IFR weather minimums to precision approach minimums of 200 feet decision-height, 1/2 mile visibility, it increases the amount of time an airport can expect to stay open during poor weather periods and thereby increases the potential number of aircraft that could and would use the airport. The lateral, vertical, and distance guidance information that aircraft equipped with the proper avionics receive improves the level of safety during landing procedures above the safety level associated with non-precision approach procedures. The microwave landing system also offers the potential for shortening the approach paths that aircraft must take when approaching the runway. In addition, the ability to handle curved approaches could also help reduce the amount of noise pollution at some locations. The opportunity to realize the shortened and curved approach benefits of MLS are limited, however, by considerations such as the willingness and ability to integrate shortened and curved approach paths into the terminal area control procedures along with straight-in and circling approaches, and the limited number of aircraft that would be suitably equipped with the necessary navigation computer equipment.

The benefit categories that will be used in developing the establishment criteria are:

Improved Safety

Reduced Flight Disruptions

If there is evidence to suggest that other benefit categories may be significant at a particular site, regional offices may furnish additional information to support a recommendation to consider additional factors in the review process.

Improved Safety Benefits

Precision landing system safety benefits are derived in Appendix F. These benefits are based on accident statistics compiled over the nine-year period from 1971 to 1979.

Safety benefits derived in Appendix F are estimated by comparing the incidence and resulting costs of non-precision approach accidents with precision approach accidents. This is done separately for aircraft classes. Accident costs are measured by the frequency and resulting costs of fatalities, injuries (serious and minor), and aircraft damage. Safety benefits of a precision landing system are the difference between the expected value of non-precision and precision approach accidents that would occur over the 15 year period subsequent to MLS implementation at a site. In this manner, benefit is calculated on the basis of the

statistical safety superiority of precision instrument approaches over non-precision approaches. The calculations were made using standard variable values adopted for FAA economic and policy analyses. These variables and their 1981 values are listed in Appendix E, Fig. E-1.

A method for deriving the number of instrument approaches to be used in estimating safety benefits involves taking actual and projected operation counts from FAA's Terminal Area Forecasts and applying a model, which is developed in Appendix C. The model estimates instrument approach counts based on the total number of annual operations at a runway, weather probabilities, the percentage of pilots equipped to make an instrument approach, and some assumptions about local versus itinerant operations.

The estimation of safety benefits requires:

- (1) finding the number of precision instrument approaches (e.g., the estimated number of instrument approaches, times the user class equipage rate, times the runway utilization factor for the runway in question),
- (2) multiplying the result obtained in the previous step above by the safety benefit unit value, and
- (3) discounting by 10 per cent to derive the present value of benefits.

The reader is reminded that this procedure is followed for each user category and then summed to arrive at a total safety benefit for the runway in question.

The safety benefit average or unit values (Step (2) above) by user class are reproduced here for the convenience of the reader.

| <u>User Category</u> | <u>Safety Benefit of Precision Approach Capability Per Precision Approach</u> |
|----------------------|---|
| Air Carrier | |
| Hub | \$ 54 |
| Non-Hub | 32 |
| Air Taxi | 180 |
| General Aviation | 35 |
| *Military | 132 |

*Estimate based on General Aviation experience. Insufficient military data did not permit independent evaluation of military accident history.

Reduced Flight Disruptions

Each precision instrument approach made when weather limits are between the nonprecision approach limits and 200-1/2, represents an avoided flight disruption which is an improvement to the case where only non-precision landings could be made. Reduced flight disruption benefits provided by a precision landing aid are the number of precision instrument approaches made when weather limits are below non-precision approach minimums by each user class, over the useful life of the aid.

Estimates of unit flight disruption costs are developed in Appendix B. The dollar value of reduced flight disruptions are based on:

- (1) the calculated number of avoided flight disruptions, i.e., additional precision instrument approaches made during each year of the analysis; and
- (2) the unit value per avoided flight disruption for each user class

The reduced flight disruption benefit includes: reduced aircraft flight time; avoided passenger handling expenses; avoided profit loss due to passenger cancellations and diversions; and saved passengers' time.

The flight-disruption cost estimating equations of Appendix B were developed by estimating aircraft and passenger delay times and airline interrupted trip expenses that are associated with various types of flight disruptions and assigning values to these costs. Average flight efficiency benefits were obtained by weighting the costs averted of each type of disruption--delay, diversion, cancellation and overflight--by its relative frequency of occurrence.

The average value of benefits per averted flight disruption, by user class, are listed below.

| | |
|------------------|---------|
| Air Carrier | |
| Hub | \$5,167 |
| Non-Hub | 2,370 |
| Air Taxi | 346 |
| General Aviation | 154 |
| Military | 428 |

Air carrier operating costs by aircraft type and the number of passengers are variables in the averted flight-disruption benefit estimating equations developed in Appendix B. Where possible, site specific estimates should be used for these variables. This requires specific aircraft mix and passenger loading data using the methods described in Appendix E. In the absence of site specific estimates, averages representative of the average passenger loadings and average aircraft operating cost of the fleet can be used for planning purposes.

In summary, the combined safety and reduced flight disruption benefits are measured by calculating the total safety benefit and the total averted flight disruption benefit and then summing them across all user classes. Specifically, the total safety benefit of having precision - approach capability BENE1 is the sum of:

1. the benefit derived from reducing the number of fatalities (BRF)
2. the benefit derived from reducing the number of minor injuries (BMI)
3. the benefit derived from reducing the number of serious injuries (BSI)
4. the benefit derived from reducing the number of aircraft destroyed (BRD)
5. the benefit derived from reducing the number of aircraft that are substantially damaged (BRS)

The total flight disruption or efficiency benefit is the sum of the averted flight disruption benefits for each user class. That is,

Total efficiency benefit (BENE2) is the sum of averted flight disruption benefits for each user class.

Total Benefit (BENET) = BENE 1 + BENE 2.

As stated earlier, a thorough derivation of the safety and efficiency benefits are found in appendices F and B, respectively.

V. Results and Impact of Precision Landing Aid Criteria

This chapter summarizes the impact of the MLS establishment/discontinuance criteria in terms of the number of runways that could be expected to meet the economic requirements for installation, given the existing aviation activity forecasts, the critical values developed in appendix E, and the other parameters used in the analysis.

Regarding the MLS program, the National Airspace System Plan states that initial funding for the program is scheduled for FY-83. Fifteen locations are scheduled to be completed by 1985, 340 additional systems by 1990 and 895 systems through 2000 for a total of 1250 systems.

Table 5-1 lists for key base years the number of runways that would meet the economic establishment criteria and identifies total initial systems and second systems at airports.

The data in Table 5-1 represent newly established systems only. In addition to these systems, there will be approximately 768 systems in the ILS inventory that will each be replaced by an MLS over time.

Systems identified by the MLS establishment criteria, combined with ILS system replacements, are expected to reach nearly 1100 ($768 + 324 = 1092$) by 1995. This number does not include those locations that could conceivably qualify for three or more systems. The results are limited to 1995 due to that being the final year in the terminal area forecasts (TAF).

TABLE 5-1 NUMBER OF NEW QUALIFYING RUNWAYS

| NATURE OF ESTABLISHMENT | YEAR CUMULATIVE NUMBER QUALIFIED | | | |
|----------------------------|----------------------------------|------|------|------|
| | 1981 | 1985 | 1990 | 1995 |
| Initial New System | 48 | 71 | 99 | 124 |
| 2nd New System | 109 | 147 | 172 | 200 |
| Total | 157 | 218 | 271 | 324 |

VI. Development of Phase I Criteria

The precision landing aid criteria, in general, establishes and defines a relationship between the level of aircraft activity during IFR conditions and the reduced potential for disrupted flights and landing accidents (i.e. avoided deaths, injuries, and damaged aircraft). Benefits of averted flight disruption and enhanced safety have been estimated in appendices B and F, respectively.

The number of AIA's needed in order to justify MLS life cycle costs can be determined for each user class for each non-precision approach minima. The breakeven activity level at each minimum and for each user class were found by solving the following equation:

$$(AX + BY)(NDF) = \$1,383,000,$$

where

A = safety benefit per instrument approach

X = instrument approaches

B = averted flight disruption benefit per instrument approach

Y = instrument approaches receiving averted flight disruption benefit (equal to X multiplied by the fraction of increased runway utilization (Table D-2)).

NDF = net discount factor: the normal 10% discount factors adjusted for growth in aviation activity (Table 6-2).

An illustration should help explain how the equation is applied.

EXAMPLE:

Assume that non-hub airport XYZ has current minima of 300-3/4. Reductions to 200-1/2 would increase the runway utilization, on average, 5.7% (See Table D-2).

Also assume that all of the instrument approaches are made by air carrier aircraft. From Appendix F, the safety benefit per instrument approach at non-hub airports is \$32.

From Appendix B, the averted flight disruption benefit per instrument approach at non-hub airports is \$2356. The net discount factor is 9.017 (from Table 6-2). Substituting the values in the equation gives

$$(32X + 2356 (.057 X))(9.017) = \$1,383,000$$

Solving for X,

$$X = \frac{1,383,000}{1507} = 918$$

or approximately 900 annual instrument approaches would be required to meet the life-cycle-costs of owning and operating an MLS at airport XYZ.

Qualifying annual instrument approaches have been found using this method for each user class and at each level of current runway non-precision approach minima utilization. This information is presented in Tables 6-1.

As outlined in Chapter II, to determine whether an airport meets the Phase I or annual instrument approach (AIA) criteria:

1. Determine the least approach minimums currently authorized for the largest aircraft using the candidate runway.
2. Reference table 6-1 to select the qualifying numbers of AIA's on the candidate runway for each user category.
3. Compute the number of recorded AIA's on the candidate runway for each user category as follows:
 - a. Determine the AIA's by an on-site survey, or.
 - b. Multiply the number of total AIA's by the percentage of airport AIA's on the candidate runway. (If site specific data are unavailable, apply 70% to first runway, 25% to second runway. For third and subsequent runways a site survey of projected IFR runway usage will be required), or
 - c. Calculate AIA's by using the SCI model developed in Appendix C.
4. Enter recorded and required AIA's for the candidate runway as indicated below. The contributions of each category toward meeting the criteria are summed. A runway with a total ratio of 1.0 or more meets the AIA criteria.

User Category

| | |
|------------------|--|
| Air Carrier | $\frac{\text{Recorded AIA's}}{\text{Required AIA's}} = x.xx$ |
| Air Taxi | $\frac{\text{Recorded AIA's}}{\text{Required AIA's}} = x.xx$ |
| General Aviation | $\frac{\text{Recorded AIA's}}{\text{Required AIA's}} = x.xx$ |
| Military | $\frac{\text{Recorded AIA's}}{\text{Required AIA's}} = x.xx$ |
| Total Ratio | x.xx |

Table 6-1

MLS Qualifying AIA Count for Stated Minimums

| <u>User Category</u> | 300-3/4 | 400-3/4 | 400-1 | 500-1 | 600-1 | 800-1 |
|----------------------|---------|---------|-------|-------|-------|-------|
| Air Carrier | | | | | | |
| Hub | 500 | 250 | 200 | 150 | 100 | 50 |
| Non-Hub | 900 | 500 | 400 | 300 | 200 | 100 |
| Air Taxi | 550 | 500 | 475 | 400 | 375 | 300 |
| General Aviation | 2700 | 2300 | 2000 | 1700 | 1400 | 900 |
| Military | 1100 | 1000 | 900 | 800 | 650 | 450 |

Table 6-2
Discounted Growth Factors*

| <u>Year</u> | <u>Discount Factor</u> | <u>IFR Growth Factors 1991-1995</u> | | | | <u>Net Discount Factors For Benefits</u> | | | |
|-------------|------------------------------|---|-----------|-----------|------------|--|-------------------------------|-------------------------------|------------------------------|
| | | <u>AC</u> | <u>AT</u> | <u>GA</u> | <u>MIL</u> | <u>AC</u> | <u>AT</u> | <u>GA</u> | <u>MIL</u> |
| 1981 | 0.953 | 1.014 | 1.160 | 1.078 | 1.000 | 0.966 | 1.105 | 1.027 | 0.953 |
| 1982 | 0.867 | 1.036 | 1.240 | 1.133 | 1.000 | 0.898 | 1.075 | 0.982 | 0.867 |
| 1983 | 0.788 | 1.072 | 1.360 | 1.244 | 1.000 | 0.845 | 1.072 | 0.980 | 0.788 |
| 1984 | 0.716 | 1.108 | 1.440 | 1.322 | 1.000 | 0.793 | 1.031 | 0.947 | 0.716 |
| 1985 | 0.651 | 1.129 | 1.600 | 1.422 | 1.000 | 0.735 | 1.042 | 0.926 | 0.651 |
| 1986 | 0.592 | 1.151 | 1.680 | 1.500 | 1.000 | 0.681 | 0.995 | 0.888 | 0.592 |
| 1987 | 0.538 | 1.165 | 1.760 | 1.578 | 1.000 | 0.627 | 0.947 | 0.849 | 0.538 |
| 1988 | 0.489 | 1.165 | 1.920 | 1.644 | 1.000 | 0.570 | 0.939 | 0.804 | 0.489 |
| 1989 | 0.445 | 1.180 | 2.000 | 1.689 | 1.000 | 0.525 | 0.890 | 0.752 | 0.445 |
| 1990 | 0.404 | 1.187 | 2.080 | 1.756 | 1.000 | 0.480 | 0.840 | 0.709 | 0.404 |
| 1991 | 0.368 | 1.209 | 2.160 | 1.811 | 1.000 | 0.445 | 0.795 | 0.666 | 0.368 |
| 1992 | 0.334 | 1.223 | 2.240 | 1.856 | 1.000 | 0.408 | 0.748 | 0.620 | 0.334 |
| 1993 | 0.304 | 1.240 | 2.330 | 1.921 | 1.000 | 0.377 | 0.708 | 0.584 | 0.276 |
| 1994 | 0.276 | 1.257 | 2.420 | 1.986 | 1.000 | 0.347 | 0.668 | 0.548 | 0.276 |
| 1995 | <u>0.251</u> <u>7.976</u> | 1.274 | 2.510 | 2.051 | 1.000 | <u>0.320</u> <u>9.017</u> | <u>0.630</u> <u>13.485</u> | <u>0.515</u> <u>11.797</u> | <u>0.251</u> <u>7.976</u> |

*Source: "FAA Aviation Forecasts, FY 1981-1992, "Table 16, Sept. 1980 (Years 1993-95 Growth Data Were Extrapolated From Prior Years Data)

VII. Sensitivity Analysis

The criteria developed in this analysis rely significantly on key assumptions, estimates, and forecasts. The result or impact of the criteria (i.e., the number of expected qualifiers), is heavily influenced by the final sets of assumptions, estimates, and forecasts that are used in the analysis. It is important to have an idea of the extent to which the analysis results could shift with possible future changes in parametric values. The approach chosen for this analysis was to vary some of the parameter values by given percentages and observe the resulting impact on the number of potential qualifiers. The number of possible parameter combinations and value changes is virtually boundless. Therefore, it was necessary to limit the extent of the test to those combinations and changes thought to be reasonable possibilities.

The values assigned some parameters are subject to more judgment and uncertainty than are others. For example, the MLS equipment cost estimates reflect the best available knowledge of equipment vendors. Actual bidding, however, may result in costs somewhat higher or lower than the current available estimates. Similarly, the aviation activity forecasters assume, as they should, that there will be no severe shocks (such as work stoppage or strikes) to the NAS system. But if and when shocks occur the value of the forecasts diminishes.

This reasoning along with the scope of the analysis dictated the selection of specific parameters used in the test. Table 7-1 summarizes the results.

It can be seen from Table 7-1 that the criteria are sensitive to significant variations in total 15-year discounted costs. In addition, if projected traffic growth disagrees significantly from what actually takes place, the impact is expected to be significant on the number of potential qualifiers. When the parameters that influence the benefits and the 15-year discounted costs are moved in opposite directions (i.e., increase benefits, decrease costs; decrease benefits, increase costs) not surprisingly, the impact is significant. The probability of the parameters varying by as much as indicated in the two combinations presented may not be very high, but it is useful to see what could result should drastic events occur. On the other hand, the criteria do not appear to be extremely sensitive to other parameters included in this test, such as changes in the number of occupants, and likelihood of accident occurrence.

TABLE 7-1
Changes in Parameter Values and Results

| | | YEAR AND IMPACT | | | |
|---|-----------------|-----------------------|--------------------|--------------------|--------------------|
| New MLS Qualifiers From Basic Analysis | | <u>1981</u> 157 | <u>1985</u> 218 | <u>1990</u> 271 | <u>1995</u> 324 |
| <u>Variable</u> | <u>% Change</u> | <u>Q¹/</u> | <u>Q</u> | <u>Q</u> | <u>Q</u> |
| Traffic Growth Rate | +10% | 173 | 240 | 297 | 357 |
| | -10% | 136 | 189 | 235 | 281 |
| 15 Yr Discounted Costs | +50% | 96 | 133 | 166 | 198 |
| | -50% | 347 | 482 | 599 | 716 |
| Number of Occupants | +25% | 164 | 228 | 283 | 338 |
| | -25% | 141 | 196 | 243 | 291 |
| Injury/Fatality Costs | +50% | 172 | 239 | 297 | 355 |
| | -50% | 142 | 197 | 245 | 293 |
| Damaged/Destroyed Aircraft Costs | +25% | 159 | 221 | 274 | 328 |
| | -25% | 155 | 215 | 268 | 320 |
| Accident Probabilities | +20% | 172 | 239 | 297 | 355 |
| | -20% | 149 | 207 | 257 | 307 |
| 15 Yr Discounted Costs | +50% | 108 | 150 | 186 | 223 |
| Injury/Fatality Costs | -50% | | | | |
| Damaged AC Costs | -25% | | | | |
| Occupants | -25% | | | | |
| 15 Yr Discounted Costs | -50% | 285 | 396 | 492 | 588 |
| Injury/Fatality Costs | +50% | | | | |
| Damaged AC Costs | +25% | | | | |
| Occupants | +25% | | | | |

1/Q = Number of new qualifiers after varying the parameter values.

VIII. A Manual Method for Computing the Phase II Precision
Landing System Establishment Benefit/Cost Ratio

To facilitate understanding of the logic incorporated in the Phase I screening process this chapter describes in detail a manual method for computing the benefit/cost ratio. Included are worksheets to show how field personnel might determine whether a runway is a candidate for MLS installation. Figure 8-1 provides a format for applying the Phase II criteria test that requires very little input data from regional offices, e.g., IFR minima, IFR use of candidate runway. Figures 8-2 through 8-10 are incorporated to illustrate and describe the step-by-step procedure for computing Phase II benefit cost ratios. This additional information is included for the reader who desires a more detailed understanding of the criteria mechanics.

The example in Figure 8-1 illustrates a one year, i.e., first year, calculation of benefits. The procedure set forth in Figure 8-1 must be repeated for each of the fifteen years in the useful life of the project. The values for each year must be multiplied by the appropriate discount factor taken from figure 8-9 and then summed to obtain 15-year discounted benefits. The 15-year discounted benefits are divided by 15-year discounted costs found in Section B of Chapter III, thus giving the B/C ratio.

FIG. 8-1

Worksheet for Application of Benefit/Cost Analysis

Location Cleveland, Ohio Runway 24R
 Airport Burke Lakefront BKL Hub (Yes/No) No
 IFR Minima: Nonprecision 500-1 MLS 200 1/2
 Increase in candidate runway use with MLS (from Table D-2) (A) 22.5%
 Estimated IFR use of candidate runway (B) 70%
 MLS-equipped IFR aircraft (C): Air Carrier 100%
 Air Taxi 100% General Aviation 98%
 Military 100%

IFR augmentation factors: (A) x (B) x (C)

Air Carrier .1575
 Air Taxi .1575
 General Aviation .1544
 Military .1575

| AVERTABLE FLIGHT DISRUPTIONS: | Airport AIAS | x | IFR AUG FACTOR | = | AVERTABLE FLT. DISR. |
|-------------------------------|-----------------|---|-------------------|---|-------------------------|
| Air Carrier | 494 | | .1575 | | 78 |
| Air Taxi | 275 | | .1575 | | 43 |
| General Aviation | 1409 | | .1544 | | 218 |
| Military | 20 | | .1575 | | 3 |

| TOTAL FLIGHT DISRUPTION BENEFIT: | COST PER DISRUPTION | x | AVERTABLE FLT. DISR. | = | FLIGHT DISRUPTION BENEFIT |
|----------------------------------|------------------------|---|-------------------------|---|---------------------------------|
| Air Carrier | \$2370 | | 78 | | \$184860 |
| Air Taxi | 346 | | 43 | | 14878 |
| General Aviation | 154 | | 218 | | 33572 |
| Military | 428 | | 3 | | 1284 |

FIG. 8-1 (Continued)

| AIA'S TO RECEIVE SAFETY BENEFITS: | TOTAL AIR- PORT AIA'S | x | (B) | (C) | = | TOTAL RW AIA's |
|--------------------------------------|----------------------------------|----------|--|----------|----------|---------------------------------|
| Air Carrier | 494 | | .70 | 1.00 | | 346 |
| Air Taxi | 275 | | .70 | 1.00 | | 193 |
| General Aviation | 1409 | | .70 | .98 | | 967 |
| Military | 20 | | .70 | 1.00 | | 14 |
| TOTAL SAFETY BENEFITS: | TOTAL RW AIA'S | x | SAFETY BENEFIT PER APPROACH | | = | TOTAL SAFETY BENEFIT |
| Air Carrier | 346 | | \$ 32 | | | \$11072 |
| Air Taxi | 193 | | 180 | | | 34740 |
| General Aviation | 967 | | 35 | | | 33845 |
| Military | 14 | | 132 | | | 1848 |
| Total | | | | | | |
| TOTAL BENEFITS: | TOTAL FLT. DIS. BENE. | + | TOTAL SAFETY BENEFITS | = | | TOTAL BENEFIT |
| Air Carrier | \$184860 | | \$11072 | | | \$195932 |
| Air Taxi | 14878 | | 34740 | | | 49618 |
| General Aviation | 33572 | | 33845 | | | 67417 |
| Military | 1284 | | 1848 | | | <u>3132</u> |
| Total 1st Year Benefits | | | | | | \$316,099 |

DETAILED MANUAL COMPUTATION OF PHASE II

The manual computation of the Phase II benefit-cost ratio quantifies the expected life-cycle benefits by discounting future year benefits and using a site-specific compound traffic growth rate. The computerized Phase II benefit/cost screening will rely on official agency traffic forecasts specific to the potential candidate site over fifteen years to derive the present value of the expected life-cycle benefits.

The analysis time frame for the criteria will normally be the latest year for which actual operation counts are available followed by 14 years of forecasts.

The benefits portion of the analysis consists of two principal benefit categories—safety benefits and averted flight disruption benefits. The method for calculating each type of benefit is described separately followed by a description of how to properly obtain the life cycle value of the benefits and also a description of how to combine the benefits information with the cost values to derive the benefit/cost ratio.

Enter in Column (A) of worksheet 8 the fifteen years to be covered in the calculations and begin with Step A below.

Step A. Calculate BRF-Reference Fig. 8-2, Worksheet 1.

1. Enter LOCID and year.
2. In column (A) enter the historical landing accident rate per non-precision instrument approach.
3. In column (B) enter the fraction of fatalities during nonprecision approach accidents.
4. In column (C) enter the average number of occupants.
5. Enter the product of columns (A), (B), and (C) in Column (D). The product is the expected number of fatalities per non-precision instrument approach.
6. In column (E) enter the historical landing accident rate per precision instrument approach.
7. In column (F) enter the fraction of fatalities during precision approach accidents.
8. In column (G) enter the product of columns (E) (F) and (G). This is the expected number of fatalities per precision instrument approach.
9. In column (H) subtract column (G) from column (D). This is the reduction in the expected number of fatalities per instrument approach.

10. Enter the expected number of precision instrument approaches in column (I).
11. Enter the value of life in column (J).
12. Multiply columns (H), (I) and (J) and enter in column (K).
13. This is the benefit of reducing the number of fatalities.
14. Sum all of the BRF's at the bottom of the page for a total BRF benefit for year (j).
15. Enter the value of BRF on Fig. 8-8.

Step B. Calculate BRMI-Ref. Fig. 8-3, Worksheet 2

1. Enter LOCID and year.
2. In column (A) enter the historical landing accident rate per non-precision instrument approach.
3. In column (B) enter the fraction of minor injuries during non-precision approach accidents.
4. In column (C) enter the average number of occupants.
5. Enter the product of columns (A), (B), and (C) in Column (D). The product is the expected number of minor injuries per non-precision instrument approach.
6. In column (E) enter the historical accident rate per precision instrument approach.
7. In column (F) enter the fraction of minor injuries during precision approach accidents.
8. In column (G) enter the product of columns (E), (F) and (G). This is the expected number of minor injuries per precision instrument approach.
9. In column (H), subtract column (G) from (D). This the reduction in the expected number of minor injuries per instrument approach.
10. Enter the expected number of precision instrument approaches in column (I).
11. Enter the value of a minor injury in column (J).
12. Multiply columns (H) (I) and (J) and enter in column (K).
13. This is the benefit of reducing the number of minor injuries.

14. Sum all of the BRMI's at the bottom of the worksheet for a total BRMI benefit for year (j).

15. Enter the value of BRMI on Fig. 8-8.

Step C. Calculate BRSI-Reference Fig. 8-4 Worksheet 3

1. Enter LOCID and year.

2. In column (A) enter the historical landing accident rate per non-precision instrument approach.

3. In column (B) enter the fraction of serious injuries during non-precision approach accidents.

4. In column (C) enter the average number of occupants.

5. Enter the product of columns (A) (B) and (C) in column (D). The product is the expected number of serious injuries per non-precision instrument approach.

6. In column (E) enter the historical accident rate per precision instrument approach.

7. In column (F) enter the fraction of serious injuries during precision approach accidents.

8. In column (G) enter the product of columns (E), (F) and (C). This is the expected number of serious injuries per precision instrument approach.

9. In column (H), subtract column (G) from (D). This is the reduction in the expected number of serious injuries per instrument approach.

10. Enter the expected number of precision instrument approaches in column (I).

11. Enter the value of a serious injury in column (J).

12. Multiply columns (H), (I), and (J) and enter in column (K).

13. This is the benefit of reducing the number of serious injuries.

14. Sum all of the BRSI's at the bottom of the worksheet for a total BRSI benefit for year (j).

15. Enter the value of BRSI on Fig. 8-8.

Step D. Calculate BRD Reference Fig. 8-5 Worksheet 4

1. Enter LOCID and year.
2. In column (A) enter the historical landing accident rate per non-precision instrument approach.
3. In column (B) enter the probability of destroying an aircraft during non-precision instrument approach accidents.
4. In column (C) enter the product of columns (A) and (B). This is the expected number of destroyed aircraft per non-precision instrument approach.
5. In column (D) enter the historical landing accident rate per precision instrument approach.
6. In column (E) enter the probability of destroying an aircraft during precision instrument approach accidents.
7. In column (F) enter the product of columns (D) and (E). This is the expected number of destroyed aircraft per precision instrument approach.
8. In column (G) subtract column (F) from column (C). This is the reduction in the expected number of destroyed aircraft per instrument approach.
9. Enter the expected number of precision instrument approaches in column (H).
10. Enter the cost of replacing an aircraft in column (I).
11. Multiply columns (G), (H) and (I) and enter in column (J). This is the benefit of reducing the number of destroyed aircraft.
12. Sum all of the BRD's at the bottom of the page for a total BRD benefit for year (j).
13. Enter the value of BRD on Fig. 8-8.

Step E. Calculate BRS-Reference Fig. 8-6 Worksheet 5

1. Enter LOCID and year.
2. In column (A) enter the historical landing accident rate per non-precision instrument approach.
3. In column (B) enter the probability of substantially damaging an aircraft during non-precision instrument approach accidents.

4. In column (C) enter the product of columns (A) and (B). This is the expected number of substantially damaged aircraft per non-precision instrument approach.
5. In column (D) enter the historical landing accident rate per precision instrument approach.
6. In column (E) enter the probability of substantially damaging an aircraft during precision instrument approach accidents.
7. In column (F) enter the product of columns (D) and (E). This is the expected number of substantially damaged aircraft per precision instrument approach.
8. In column (G) subtract column (F) from column (C). This is the reduction in the expected number of substantially damaged aircraft per instrument approach.
9. Enter the expected number of precision instrument approaches in column (H).
10. Enter the cost of restoring a substantially damaged aircraft in column (I).
11. Multiply columns (G), (H) and (I) and enter in column (J). This is the benefit of reducing the number of substantially damaged aircraft.
12. Sum all of the BRS's at the bottom of the page for a total BRS benefit for year (j).
13. Enter the value of BRS on Fig. 8-8.

LOC ID _____
 SUB (YES/NO) _____
 YEAR _____

FIGURE 8-2
 Computation of Reduced Fatalities Benefit - BRP

| Worksheet 1 | | | | | | | | | |
|------------------|-----------|-----------|-----|------------------|----------|--------|------------------|-----------|-----------------------------|
| | (A) | (B) | (C) | (D) | (E) | (F) | (G) | (H) | (I) |
| | R_{np} | FF_{np} | Occ | $(A) \times (B)$ | R_p | FF_p | $(E) \times (F)$ | $(D)-(G)$ | PIA |
| | | | | $\times (C)$ | | | $\times (C)$ | | CF |
| | | | | | | | | | $(H) \times (I) \times (J)$ |
| | | | | | | | | | = BRP |
| Air Carrier | .0000153 | .0968 | | | .0000031 | .3549 | | | |
| Air Taxi | .00001458 | .3167 | | | .0000250 | .3922 | | | |
| General Aviation | .0000925 | .2976 | | | .0000261 | .5597 | | | |
| Military | .0000925 | .2976 | | | .0000261 | .5597 | | | |
| TOTAL | | | | | | | | | |

$$BRP = ((R_{np} \times FF_{np} \times Occ) - (R_p \times FF_p \times Occ)) \times PIA \times CF$$

I
 AC, GA
 AT, MIL

LOC ID
RUB (YRS/NO)
YEAR

FIGURE 8-3
Computation of Reduced Minor Injuries Benefit - BMMI

Worksheet 2

| | (A) R_{mp} | (B) FMI_{mp} | (C) Occ | (D) \times (B) \times (C) | (E) R_p | (F) FMI_p | (G) \times (F) \times (C) | (H) \times (G) \times (D) - (G) | (I) \times (H) \times (J) - (I) | (J) CP | (K) \times (I) \times (J) \times BMMI |
|------------------|-----------------|-------------------|------------|----------------------------------|--------------|----------------|----------------------------------|--|--|-----------|---|
| Air Carrier | .0000153 | .0623 | | | .0000031 | .0835 | | | | | |
| Air Taxi | .00001458 | .1334 | | | .0000290 | .1569 | | | | | |
| General Aviation | .0000925 | .0885 | | | .0000261 | .1276 | | | | | |
| Military | .0000925 | .0885 | | | .0000261 | .1276 | | | | | |
| TOTAL | | | | | | | | | | | |

$$BMMI = ((R_{mp} \times FMI_{mp} \times Occ) - (R_p \times FMI_p \times Occ)) \times PIA \times CHI$$

I
AC, AT
GA, MIL

LOC ID
 SUB (YR/MO)
 YEAR

FIGURE 8-4
 Computation of Reduced Serious Injuries Benefit - BRSI

Worksheet 3

| | (A) | (B) | (C) | (D) | (E) | (F) | (G) | (H) | (I) | (J) | (K) |
|------------------|-----------|-------------|-----|----------------------------------|----------|---------|----------------------------------|-----------|-----|-----|---|
| | R_{top} | FSI_{top} | Occ | $(A) \times (B)$ $\times (C)$ | R_p | FSI_p | $(E) \times (F)$ $\times (C)$ | $(D)-(G)$ | PIA | CSI | $(H) \times (I) \times (J)$ $= BRSI$ |
| Air Carrier | .0000153 | .0872 | | | .0000031 | .0626 | | | | | |
| Air Taxi | .0001458 | .1167 | | | .0000250 | .1373 | | | | | |
| General Aviation | .0000925 | .0804 | | | .0000261 | .1648 | | | | | |
| Military | .0000925 | .0804 | | | .0000261 | .1648 | | | | | |

TOTAL

$$BRSI = ((R_{top} \times FSI_{top} \times Occ) - (R_p \times FSI_p \times Occ)) \times PIA \times CSI$$

I
 NC, WA
 AT, MIL

LOC ID _____
 SUB (YES/NO) _____
 YEAR _____

FIGURE 8-5
 Computation of Reducing Number of Destroyed Aircraft Benefit - BND
 Worksheet 4

| | (A) R_{np} | (B) DR_{np} | (C) $(A) \times (B)$ | (D) R_p | (E) DR_p | (F) $(D) \times (E)$ | (G) $(C) - (F)$ | (H) PIA | (I) $CRPL$ | (J) $(G) \times (H) \times (I)$ = BND |
|------------------|-----------------|------------------|-------------------------|--------------|---------------|-------------------------|--------------------|--------------|---------------|---|
| Air Carrier | .0000153 | .2778 | .0000425 | .0000031 | .4737 | .0000147 | .0000278 | | | |
| Air Taxi | .0001458 | .4058 | .0000582 | .0000250 | .5926 | .00001481 | .00004439 | | | |
| General Aviation | .0000925 | .4239 | .00003921 | .0000261 | .7054 | .00001481 | .00002080 | | | |
| Military | .0000925 | .4239 | .00003921 | .0000261 | .7054 | .00001481 | .00002080 | | | |
| TOTAL | | | | | | | | | | |

Σ
 AC, AT
 GA, MIL

$$BND = ((R_{np} \times DR_{np}) - (R_p \times DR_p)) \times PIA \times CRPL$$

LOC ID
BRS (YR/MO)
YEAR

FIGURE 8-6
Computation of Reducing Number of Substantially Damaged Aircraft Benefit - BRS
Worksheet 5

| | (A) | (B) | (C) | (D) | (E) | (F) | (G) | (H) | (I) | (J) |
|------------------|-----------|-----------|------------------|----------|--------|------------------|-------------|-----|-------|--------------------------------------|
| | R_{np} | SR_{np} | $(A) \times (B)$ | R_p | SR_p | $(D) \times (E)$ | $(C) - (F)$ | PIA | CREST | $(G) \times (H) \times (I)$ = BRS |
| Air Carrier | .0000153 | .7222 | .00001105 | .0000031 | .5263 | .00000163 | .00000942 | | | |
| Air Taxi | .00001458 | .5942 | .0000866 | .0000250 | .4074 | .00001019 | .00007641 | | | |
| General Aviation | .0000925 | .5761 | .0000533 | .0000261 | .2946 | .0000077 | .0000533 | | | |
| Military | .0000925 | .5761 | .0000533 | .0000261 | .2946 | .0000077 | .0000533 | | | |

Σ
AC, AT
GA, MIL

TOTAL

$$BRS = (R_{np} \times SR_{np}) - (R_p \times SR_p) \times PIA \times CREST$$

The calculation of averted flight disruption, or efficiency, benefits involves the valuation of the time saved and expenses avoided when the presence of a precision landing aid increases the ability of airports to receive landing aircraft during IFR weather conditions. Monetary benefits are credited to the additional instrument approaches, made possible by the presence of the precision aid, that otherwise would not have been possible.

The step by step procedures for calculating averted flight disruption benefits for a specific site or runway are described below.

1. When possible determine the fleet mix that is expected to utilize the runway in question. Otherwise, substitute the national fleet composition that is provided by headquarters.
2. Based on the fleet mix, identify the average number of passengers by user class. One method for deriving this value is described in the critical values appendix. (Note: The number of passengers and occupants are equal for the general aviation and military user classes.
3. For each user class, using the averted flight disruption cost equations developed in appendix B, and the appropriate number of passengers for each user class, compute the value of an averted flight disruption.
4. For each year (j) and each user class (i) calculate the number of annual instrument approaches using the model and equations developed in appendix C.
5. Calculate the additional percentage of time the airport or runway is expected to be open due to the reduction in minima, i.e., the weather improvement factor. Employ the methods described in appendix D.
6. Select the appropriate avionics equipment rate for each user class. The equipment rates have been determined as follows:

| | | |
|------------------|---|------|
| Air Carrier | - | 100% |
| Air Taxi | - | 100 |
| General Aviation | - | 98 |
| Military | - | 100 |

7. Apply the appropriate runway utilization factor: 70% if it is the first precision landing system at the airport, 25% if it is the second (provided that site-specific factors are unavailable).

Mathematically, the benefits of averted flight disruptions are measured by the following relationship:

$$VFD(i) \times AIA(i, j) \times Wx \times EQR(i) \times RU = BFD(i)$$

where

VFD(i) = the value of an averted flight disruption for the i^{th} user class ($i = 1, 2, 3, 4, 5$; 1 = air carrier hub, 2 = air carrier non-hub, 3 = air taxi, 4 = general aviation, 5 = military).

AIA(i, j) = annual instrument approaches for the i^{th} user class in the j^{th} year.

W_x = the additional percentage of time the airport would be open after the minima were lowered, i.e., the weather improvement factor.

EQR(i) = the avionics equipage rate for the i^{th} user class.

RU = the runway utilization factor: 70% if runway represents the first precision landing aid at the airport, 25% if it represents the second (when site-specific values are not available).

BFD(i, j) = the averted flight disruption benefits for the i^{th} user class in the j^{th} year.

Worksheets are provided to facilitate the manual computation of these values as well. A copy of the worksheet and instructions for its use are included below.

Step F. Calculate BFD-Reference Fig. 8-7, Worksheet 6

1. Enter LOCID and year.
2. In column (A) enter the value of an averted flight disruption for each user class.
3. In column (B) enter the number of annual instrument approaches for each user class.
4. In column (C) enter the weather improvement factor (the result of reducing minima to 200 1/2 from existing levels).
5. In column (D) enter the avionics equipage rate for each user class.
6. In column (E) enter the runway utilization factor.
7. In column (F) enter the product of columns (A), (B), (C), (D) and (E). This is the total flight disruption benefit for a runway in the reference year for each user class.
8. Sum all the values of column (F) and enter at the bottom of the page. This is the total flight disruption benefit for the runway in the reference year.

STEP G - Computation of Total Annual Benefit, Fig. 8-8, Worksheet 7.

1. Sum all of the safety benefit values to obtain Bene 1.
2. Find the total flight disruption (efficiency) benefit on worksheet 6 and enter it on worksheet 7. This is Bene 2.
3. Add Bene 1 to Bene 2 to obtain Bene T, the total benefit for the reference year.

STEP H - Computation of Present Value of Benefits, Fig. 8-9, Worksheet 8.

1. Enter the BeneT's for each year in column (B).
2. Multiply the values by the corresponding discount factor found in column (C) and enter the results in column (D).
3. Sum all of the discounted present value benefits of column (D) to obtain total discounted present value benefits, BENEPV

STEP I - Computation of Present Value of Costs, and Benefit/Cost Ratio, Fig. 8-10, worksheet 9

1. Enter the value for BENEPV found in STEP H in the blank space provided on worksheet 9.
2. The ratio BENEPV/COSTPV gives the benefit/cost ratio.

FIGURE 8-7

COMPUTATION OF AVERTED FLIGHT DISRUPTION BENEFIT - BFD

Worksheet 6

| LOC ID | (A) | (B) | (C) | (D) | (E) | (F) |
|--------------|--------|----------|-----|--------|-----|-----------------------------|
| Hub (YES/NO) | | | | | | (A) x (B) x (C) x (D) x (E) |
| Year | VFD(i) | AIA(i,j) | Wx | EQR(i) | RU | = BFD(i) |

Air Carrier

| | |
|---------|--------|
| Hub | \$5167 |
| Non Hub | \$2370 |

| | |
|----------|--------|
| Air Taxi | \$ 346 |
|----------|--------|

| | |
|------------------|--------|
| General Aviation | \$ 154 |
|------------------|--------|

| | |
|----------|--------|
| Military | \$ 428 |
|----------|--------|

Total

FIGURE 8-8

COMPUTATION OF TOTAL ANNUAL BENEFIT

WORKSHEET 7

Total Safety Benefit

$$\text{Benel} = \text{BRF} + \text{BRMI} + \text{BRSI} + \text{BRD} + \text{BRS}$$

$$= \underline{\quad} + \underline{\quad} + \underline{\quad} + \underline{\quad} + \underline{\quad} = \underline{\quad}$$

Total Efficiency Benefit

$$\text{Bene2} = \sum_{i=1}^5 \text{BFD}(i) = \underline{\quad}$$

Total Benefit

$$\text{Benel} + \text{Bene2} = \underline{\quad} + \underline{\quad} = \underline{\quad} = \text{BENET}$$

FIGURE 8-9

Computation of Present Value of Benefits - BENEPV

Worksheet 8

LOCID ____.

| (A) | (B) | (C) | (D) |
|------|------------------------------|-----------------------------------|----------------------------|
| YEAR | TOTAL BENEFIT BENET (\$K) | DISCOUNT FACTOR (BASED ON 10%) | PRESENT VALUE (B) x (C) |
| 1. | | 0.953 | |
| 2. | | 0.867 | |
| 3. | | 0.788 | |
| 4. | | 0.716 | |
| 5. | | 0.651 | |
| 6. | | 0.592 | |
| 7. | | 0.538 | |
| 8. | | 0.489 | |
| 9. | | 0.445 | |
| 10. | | 0.404 | |
| 11. | | 0.368 | |
| 12. | | 0.334 | |
| 13. | | 0.304 | |
| 14. | | 0.276 | |
| 15. | | 0.251 | |

TOTAL

BENEPV =

FIGURE 8-10

Computation of Present Value of Costs and Benefit/Cost Ratio

Worksheet 9

LOCID _____

MLS Establishment

$$\text{COSTPV} = (7.976 \times \text{COSTA}) + \text{COSTI}$$

$$\text{COSTPV} = (7.976 \times 56,000) + \$936,000$$

$$\text{COSTPV} = (446,656 + 936,000 = \$1,382,656$$

$$\text{COSTPV} = (\$1383 \text{ Thousands of Dollars})$$

Benefit/Cost Ratio

$$\text{BENEPV/COSTPV} = \$______/\$1383$$

$$= ______$$

Bibliography

1. Airway Planning Standard Number One - Terminal Air Navigation Facilities and Air Traffic Control Services, FAA Order 7031.2B.
2. Economic Analysis of Investment and Regulatory Decisions - A Guide, Report No. FAA-APO-82-1.
3. Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs, Report Number FAA-APO-81-3.
4. Establishment Criteria for Category I Instrument Landing System (ILS) Report No. FAA-ASP-75-1 December 1975.
5. An Analysis of the Requirements for and the Benefits and Costs of the National Microwave Landing System. Volumes I and 2, and Executive Summary, FAA, Office of Systems Engineering Management Report No. FAA-EM-80-7, June 1980.
6. Life-Cycle-Cost Analysis of the Microwave Landing System Ground and Airborne Systems, FAA, Office of Systems Engineering Management and Systems Research and Development Service, Report No. DOT/FAA/RD-87-96 October 1981.
7. Microwave Landing System (MLS) Implementation, Volumes I and II, Radio Technical Commission for Aeronautics SC-125, Document No.-166, July 1977.
8. Establishment and Discontinuance Criteria for Airport Traffic Control Towers, Draft Report, FAA, APO, February 1982.
9. Investment Criteria for Airport Surveillance Radar (ASR/ATCRBS/ARTS) Report No. FAA-APO-81-13, November 1981.
10. Microwave Landing System Transition Plan Report No. FAA-APO-81-1 July 1981.
11. Microwave Landing System Applications and Benefits J.S. Matney, Mitre Corporation, July 1975.
12. Utilizing Facilities Master File Data for Microwave Landing System Implementation, T. L. Croswell, October 1974.
13. MLS Case Studies at Major Air Carrier Airports MITRE Corporation, A.P. Smith, August 1976.
14. MLS Noise Reduction Case Studies at Selected Air Carrier Airports Mitre Corporation, F.A. Amodeo, January, 1977.
15. Microwave Landing System (MLS) Implementation Volumes I and II, Radio Technical Commission for Aeronautics, July 1977.

Appendix A

Previous Precision Landing System Establishment Criteria

The Instrument Landing System (ILS) Criteria published in 1975 replaced the old set of ILS criteria that set a requirement for minimum airport activity levels as the justification for the installation of the ILS. The 1975 criteria incorporated airport activity into a methodology for computing economic benefits and ultimately benefit/cost comparison criteria. These criteria are reproduced below.

The new MLS criteria reflect the most recent FAA approved set of critical values. In addition, unlike in the previous criteria where the safety benefits are measured primarily as a function of the reduction in the incidence of accidents, the new criteria improve upon this measure by taking into account the differences in the severity of non-precision approach and precision accidents.

Previous ILS Establishment Criteria1. Establishment

An airport where scheduled air carrier turbojet operations are conducted on a sustained basis, or any other airport which meets the annual instrument approach criteria in paragraph 2, is a candidate for Category I ILS with an approach light system. (Provisions that are not relevant to this discussion have been omitted, e.g., the operation must be safe, runway lights are required, etc.)

2. Annual Instrument Approach Criteria

An airport is a candidate for an initial or a multiple ILS with approach lights when the annual instrument approaches recorded for the runway on which the ILS is to be installed meet or exceed any combination of the conditions shown in Table A-1.

3. Benefit/Cost Screening

ILS candidates identified by the above procedures will be screened in FAA Headquarters using the benefit/cost technique described in this report. FAA regional offices shall submit data required for screening purposes with their responses to the annual Call for Estimates. This provision does not apply to airports that qualify for an initial ILS under the air carrier turbojet service criterion.

TABLE A-1

Annual Instrument Approach Criteria

| User Category | Nonprecision Approach Minimums on the Candidate ILS Runway | | | | | |
|---------------------|---|----------------|--------------|--------------|--------------|--------------|
| | <u>300-3/4</u> | <u>400-3/4</u> | <u>400-1</u> | <u>500-1</u> | <u>600-1</u> | <u>700-1</u> |
| *Air Carrier | | | | | | |
| Large Hub | 300 | 200 | 150 | 100 | 75 | 50 |
| Medium Hub | 400 | 250 | 200 | 150 | 100 | 75 |
| Small Hub | 500 | 300 | 250 | 175 | 125 | 100 |
| Nonhub | 1,000 | 600 | 500 | 350 | 250 | 200 |
| Air Taxi | 750 | 550 | 475 | 375 | 300 | 225 |
| General Aviation | 2,500 | 2,000 | 1,800 | 1,500 | 1,200 | 900 |

NOTE: These AIA levels apply only when the ILS will give minimums of 200-1/2 or the equivalent; if lesser minimums are achievable, consult with the Office of Aviation Policy and Plans to determine procedures (criteria) that are applicable.

To determine whether an airport meets Annual Instrument Approach (AIA) criteria:

- o Determine the least approach minimums currently authorized for the largest aircraft using the candidate runway, e.g., 500-1.
- o Reference the above table to select the qualifying numbers of AIA's on the candidate runway for each user category, e.g., small hub - 175, air taxi - 375, general aviation - 1500.*
- o Compute the number of recorded AIA's on the candidate runway for each user category as follows:
 1. Determine the AIA's by an on-site survey; or
 2. Calculate the AIA's by estimating the percentage of the total airport AIA's that used the candidate runway. Multiply this percentage by the total airport AIA's to determine the recorded AIA's.
- o Enter recorded and qualifying AIA's for the candidate runway as indicated below. The contribution of each category toward meeting the criteria is determined by summation. A runway with a total ratio of 1.0 or more meets the AIA criteria.

*Hub designation is determined by enplanements at candidate airports.

User Category

| | | |
|-------------------|---|-------------|
| Air Carrier: | $\frac{\text{Recorded AIA's}}{\text{Qualifying AIA's}} =$ | x.xx |
| Air Taxi: | $\frac{\text{Recorded AIA's}}{\text{Qualifying AIA's}} =$ | x.xx |
| General Aviation: | $\frac{\text{Recorded AIA's}}{\text{Qualifying AIA's}} =$ | <u>x.xx</u> |
| Total Ratio | | x.xx |

4. Discontinuance

- a. At an airport where scheduled air carrier turbojets operate the ILS shall not be decommissioned. At an airport where air carrier turbojet operations are discontinued and are not forecast to be resumed, the discontinuance criteria in 4(b) shall apply.
- b. Airports having no scheduled air carrier turbojet operations are candidates for decommissioning of an ILS when the instrument approach activity falls to two-thirds* of the qualifying level. The decommissioning of an ILS shall be justified by a benefit/cost study.

Provisions for installing ILS at remote locations, for training, and for noise abatement have been retained.

*Annual O&M costs are about two-thirds of prorated investment costs.

APPENDIX B

BENEFITS OF REDUCED FLIGHT DISRUPTION

I. INTRODUCTION

Landing aids can help reduce flight disruptions by lowering landing minima. A landing aircraft can descend to 200 feet before attempting to land with a precision landing system. In contrast, a non-precision system typically allows descents only to 500 or 600 feet. To compute the benefit of a landing aid, the number of flights for which the aid avoids disruption is calculated, and multiplied by the unit cost of the disruption. This appendix develops that cost. Costs have been developed separately for air carrier, air taxi, general aviation, and military. Costs for air carrier aircraft are also separated by whether the flight is operating at a hub or nonhub airport. Benefits for reduced disruptions are based on assumed operating scenarios that describe the flow of events when a flight is disrupted because the destination weather is below landing minima.

When weather conditions are so poor that the possibilities of a safe landing are doubtful, one of four things can happen depending upon the circumstances: (1) an aircraft can circle the airport until conditions improve (delay); if poor conditions persist, the pilot may choose either to (2) fly to a nearby airport where conditions are better (diversion), or (3) in the case of a multi-legged flight, continue to the next scheduled stop (overflight); (4) if poor weather is forecast for an extended period, a flight may be canceled (cancellation).

Weather-caused flight disruptions--delays, diversions, overflights, and cancellations--impose economic penalties on both aircraft operators and users. Delays and diversions increase aircraft operating costs, while overflights and cancellations result in loss of revenue. In addition, extra passenger-handling expenses result from each type of disruption. Passengers themselves suffer inconvenience and delay.

II. AIR CARRIER FLIGHT DISRUPTIONS

A. Scenario Development

Flight disruptions of air carrier flights vary depending on the length of the flight, and whether the destination airport is a hub. In long-haul operations, airlines seldom cancel because the destination airport is forecast to be closed. If on arrival the destination airport is forecast to open within thirty minutes or so, the aircraft will hold. Otherwise, it will divert to another airport.

Short-and medium haul flights tend to take delays on the ground at the departure airport to conserve fuel and to ease congestion problems at destination. This saves equipment operating costs but not crew costs nor

the cost of passenger delay time. If the below-minima weather at the destination is forecast to persist, the flight may be canceled. If the airport is an intermediate stop along a route, it may be overflowed, creating a diversion for passengers intending to land and a cancellation for those expecting to board the aircraft.

Airport facilities also affect flight scenarios. Most hub airports have precision approaches with lower landing minima, and with lower minima, the chance that the weather will improve in the short term is greater. Additionally, most hubs are served by larger aircraft, on the average, than small airports, making diversion or cancellation costs relatively high. Consequently, flights into large airports are more likely to be delayed rather than diverted or canceled, than are flights into small airports. Because of these differences, separate flight disruption cost estimating equations have been developed for hub airports and for non-hub airports.

B. Air Carrier Delays

A sample of National Airspace Command Center (NASCOM) reported delays was examined for the six quarter period from the beginning of 1980 to mid year 1981.^{1/} It included days when below minima weather caused a significant number of delays of varying durations, as well as days where the number of weather-caused delays were comparably smaller. Analysis revealed that average delays are 45 minutes at hub airports (30 minutes at non-hub airports). The 45 minutes are broken down into 15 minutes airborne and 30 minutes ground delay, based on FAA's Central Flow Control goal to limit airborne delay to an average of 15 minutes.

B1. Costs Associated With Passengers: Passengers on the delayed flight will be delayed in and with the aircraft for 45 minutes at hubs, 30 at non-hubs. But passengers on a following flight may also be delayed because the aircraft was late arriving to pick them up. Equipment turnaround time, however, normally includes about 15 minutes of slack time. By foregoing scheduled slack time at intermediate stops, delayed flights are able to make up some lost time during subsequent legs. Nevertheless, boarding passengers would still have waited for the delayed flight, and be delayed as much as passengers on the preceding legs, less the time made up due to foregone slack time.

An expression for passenger delay can be derived by examining what happens to each passenger on an aircraft while it is delayed, and to each subsequent passenger. A sample of 624 flights from the Official Airline Guide was analyzed to estimate that, on the average, an aircraft arriving at a destination has one additional destination to serve. (Some destinations are the final one for that flight, while flights to other destinations have several additional destinations.) Given a delay on the initial leg of L minutes, the n passengers on that leg experience an L-minute delay. On the remaining leg of the flight, the passengers experience a delay of L-15 minutes. The total delay is therefore approximately $n \times (2L-15)$. For L equals 45 minutes delay at hub airports, the total delay is 1.25 hours \times n passengers.

^{1/}NASCOM contains statistics only for flight delays exceeding 30 minutes. NASCOM data are considered appropriate for MLS analysis as weather-caused flight disruptions are typically of this duration or longer.

The situation is slightly different at non-hub airports, because it is assumed that half of the passengers are through passengers, and are only delayed once. For a thirty minute delay on the leg to the non-hub destination, all of the passengers are delayed thirty minutes ($30 \times n$). The $n/2$ boarding passengers on the next leg get the benefit of the 15 minute foregone slack time and are delayed $n/2 \times 15$ minutes.

But the $n/2$ through passengers who experienced the initial 30 minute delay will enjoy the 15 minutes worth of slack time that is foregone, thus, reducing their total delay to 15 minutes also. The total delay, then is $(n/2 \times 30) + (n/2 \times 15) + (n/2 \times 15) = 15n + 7.5n + 7.5n = 30n$ or .5 hours $\times n$ passengers.

B2. Costs Proportional to Aircraft Hours:

When an aircraft is delayed on the ground at a hub airport, the carriers incur crew costs. When it is airborne, full aircraft operating costs are incurred. The ground delay costs incurred by airlines are partially offset by their ability to forego scheduled slack time. The 15 minutes worth of slack time assumed in the passenger delay analysis is also assumed for the aircraft ground delay, so that the thirty minute estimated ground delay is reduced to 15 minutes. The percentage of total aircraft variable-operating costs attributable to crew was determined from data on pp. 55-59 in Reference B-5. Crew costs account for approximately 26% of aircraft operating costs. Using the term AOC_1 for aircraft hourly operating cost at hub airports, the following expressions result:

| | |
|---------------------|-------------------------------------|
| For Airborne Delay: | .25 hours $\times AOC_1$ |
| For Ground Delay: | .25 hours $\times .26 \times AOC_1$ |
| Total: | .32 $\times AOC_1$ |

Similarly for non-hub airports, with the 30 minute delay apportioned into airborne delays of 10 minutes and ground delays of 20 minutes less 15 minutes of foregone slack time, and AOC_2 representing the operating cost of aircraft at non-hubs:

| | |
|---------------------|-------------------------------------|
| For Airborne Delay: | .17 hours $\times AOC_2$ |
| For Ground Delay: | .08 hours $\times .26 \times AOC_2$ |
| Total: | .19 $\times AOC_2$ |

B3. Summary Air Carrier Delay Costs:

Combining the expressions above, the total cost per delayed air carrier aircraft for a value of passengers time equal to (V_{PT}) , is estimated to be

| | |
|--------------|--------------------------------|
| at hubs: | $(1.25 V_{PT}) n + 0.32 AOC_1$ |
| at non-hubs: | $(.5 V_{PT}) n + 0.19 AOC_2$ |

C. Air Carrier Cancellations

Unless extremely poor weather is forecast to remain for several hours, airlines do not cancel flights. But given a flight cancellation, the airline incurs passenger handling expenses, and passengers suffer delay. The airline also suffers lost profit, losing the revenue from the flight while saving its operating costs.

C1. Costs proportional to aircraft hours: There are two costs proportional to aircraft hours of operation - the cost saved when the airline does not have to operate the flight, and the cost incurred when the canceled flight must be repositioned for a future flight.

Trunk airlines are more typical of those operating at hub airports, while local service airlines are more the norm at non-hubs. The average duration of a trunk air carrier aircraft flight in FY 1978 was 1.25 hours, and that length was taken as the hours of operation avoided by a flight canceled at a hub airport. Local service durations were assumed for non-hubs, an average of 0.58 hours.

Aircraft sometimes must be repositioned after a cancellation. An average of 1/2 hour extra flying time for the repositioning is assumed, and it is estimated that 1/3 of canceled aircraft must be repositioned. Averaged for all cancellations, this yields ten minutes extra flying time per cancellation (1/2 hour applied to 1/3 of the cancellations).

The following expressions of cost to the air carrier from cancellations result from the above analysis:

| | Hub | Non-hub |
|-----------------------------------|--------------------------|--------------------------|
| Repositioning aircraft (1/6 hour) | 0.167 AOC ₁ | 0.167 AOC ₂ |
| Less direct operating savings | - 1.25 AOC ₁ | - 0.58 AOC ₂ |
| Total | - 1.083 AOC ₁ | - 0.413 AOC ₂ |

These net values actually represent the operating cost savings that result from a cancelled flight. The true profit loss would be reduced by these amounts.

C2. Costs Associated With Passengers: There are two costs associated with passengers, the lost revenue, which is a cost to the airline, and the delay, which is a cost to the passenger.

The prospective passenger must decide whether to schedule another flight, cancel his trip altogether, or seek alternate modes of transport. If the passenger elects to wait for the next available flight, the airline, or air carriers taken as a whole, retain the passenger's ticket revenue with little added expense, since flights do not generally operate at capacity. If the passenger does not continue by air, the revenue is lost to air carriers. Based on discussions with airline personnel, United Research (B-3) developed estimates of the percentage of passengers who, after a cancellation, ended up on another flight. The estimates ranged

from 30% for short trips, to 80% on longer trips. Today's airline personnel could not update or verify these percentages. Because the reliability and speed of air transportation has been improved, however, 80% -- the upper end of the United Research range -- was assumed for this study. This is expressible as a per passenger cost to the airline of 20% of the average revenue per passenger, expressed as .2 RPC.

It was determined through conversations with airline operations personnel that passengers waiting for flights that are later cancelled could easily have already spent two hours at an airport waiting for the weather to improve. After the weather improves, passengers must wait for the next available flight, which, according to the same sources, could easily add three hours of delay. It is assumed, then, that on average a cancelled flight results in a total of five hours of delay per passenger. This delay applies to the estimated eighty per cent of those passengers thought to continue with their original plans to fly and also the remaining passenger, who divert to surface transportation modes.

The per passenger costs are:

| | |
|------------------------|-----------------------|
| Extra handling expense | VCLC |
| Revenue Loss | .2 RPC |
| Lost time (5 hours) | 5 VPT |
| Total | 5 VPT + VCLC + .2 RPC |

C3. Summary Costs of Air Carrier Cancellations:

The following expressions sum the costs for passengers and aircraft operating costs derived above

for hubs: $(5 \text{ VPT} + \text{VCLC} + .2 \text{ RPC})n - 1.083 \text{ AOC}_1$
for non-hubs: $(5 \text{ VPT} + \text{VCLC} + .2 \text{ RPC})n - 0.413 \text{ AOC}_2$

Cancellation of a flight results, an estimated one half of the time, in a cancellation of the following trip which the aircraft was scheduled to serve. Therefore, the expressions are multiplied by 1.5.

For hubs: $1.5 ((5 \text{ VPT} + \text{VCLC} + .2 \text{ RPC})n - 1.083 \text{ AOC}_1)$
For non-hubs: $1.5 ((5 \text{ VPT} + \text{VCLC} + .2 \text{ RPC})n - 0.413 \text{ AOC}_2)$

D. Air Carrier Diversions

D1. Costs proportional to aircraft hours: Arriving aircraft may divert to another airport if below minima weather is forecast for extended periods. Diverting aircraft is costly. Additional flying time in holding over the original destination airport and then flying to an alternate destination was estimated to average one hour. After the weather improves, the aircraft usually must be ferried to another airport before it resumes scheduled operations, for an additional estimated half-hour. The total additional flight time per diversion is therefore estimated at 1-1/2 hours, or 1.5 AOC_1 .

D2. Costs Associated With Passengers: It is also necessary to consider lost passenger time in assessing diversion impacts. One hour is immediately lost because of additional flight time. To this must be added the additional time required for the passenger to reach his desired destination. This may take the form of air or surface transportation and may involve providing passengers meals and overnight lodging. If the return trip is by air, an extra hour of flight time is estimated plus two hours of waiting for the destination airport to accept arriving aircraft. Similar amounts of time are likely for surface transportation. Total time lost due to a flight disruption thus adds up to four hours per passenger. Airlines incur extra passenger-handling expenses of food, housing, and return-trip fare. The per passenger expense is thus:

| | |
|------------------------|----------------------|
| Extra handling expense | V_{DVC} |
| Lost time (4 hours) | $4 V_{PT}$ |
| Total | $4 V_{PT} + V_{DVC}$ |

D3. Secondary Effects of Diversions: At non-hub airports, there is a secondary effect, because the following trip on which the aircraft was scheduled to depart may be canceled. From fragmentary information obtained from airline data, it was estimated that this occurs on half of the non-hub flights. The cancellation cost developed above in Section C suggests that the per passenger costs in a cancellation are:

$$5 V_{PT} + V_{CLC} + .2 \text{ RPC}$$

The direct aircraft operating cost savings from avoiding the canceled leg are $0.58 AOC_2$. Combining these terms, and multiplying by .5 to account for the estimate that half of the flights are affected, the secondary effect of a diversion at a non-hub airport is:

$$0.5 ((5 V_{PT} + V_{CLC} + .2 \text{ RPC})n - 0.58 AOC_2)$$

D4. Summary Air Carrier Diversion Costs:

Hubs: combining the terms derived above, the costs associated with the diversion of an air carrier aircraft from a hub airport is:

$$(4 V_{PT} + V_{DVC})n + 1.5 (AOC_1)$$

At non-hubs:

$$(4 V_{PT} + V_{DVC})n + 1.5 (AOC_2) + 0.5 ((5 V_{PT} + V_{CLC} + .2 \text{ RPC})n - 0.58 AOC_2)$$

or
$$(6.5 V_{PT} + V_{DVC} + .5 (V_{CLC} + .2 \text{ RPC}))n + 1.21 AOC_2$$

E. Air Carrier Overflights

Overflight costs apply at non-hub airports only. An overflight does not increase aircraft operating costs; in fact, when a stop is bypassed and the aircraft proceeds directly to its next destination, total flying time is reduced. These savings are offset in those instances when the pilot holds for a few minutes over his intended destination while he decides whether he should or should not attempt a landing.

An overflight results in a diversion for passengers intending to deplane and a cancellation for passengers intending to board the aircraft. The airlines incur extra passenger handling expenses when stops are overflowed, just as they do with other diversions and cancellations; and passengers, whether enplaning or deplaning, experience delays. For these reasons, in this study an overflight has been equated to a diversion plus a cancellation and, except for increased aircraft operating costs, costed accordingly.

E1. Costs associated with passengers:

| | |
|----------------------------|---------------------------------------|
| For diverted passengers; | |
| Passenger handling expense | V_{DVC} |
| Lost time (4 hours) | $4 V_{PT}$ |
| | <hr/> |
| Total | $4 V_{PT} + V_{DVC}$ |
| For canceled passengers; | |
| Passenger handling expense | V_{CLC} |
| Lost time (5 hours) | $5 V_{PT}$ |
| Revenue Loss | $.2 \text{ RPC}$ |
| | <hr/> |
| Total | $5 V_{PT} + V_{CLC} + .2 \text{ RPC}$ |

E2. Summary Cost of Air Carrier Overflights:

$$(9 V_{PT} + V_{DVC} + V_{CLC} + .2 \text{ RPC})n$$

where n is the number of passengers.

F. Relative Frequency of Flight Disruptions

In this section the relative distribution of the flight disruption categories is derived so that the cost equations determined above for each kind of disruption, can be weighted and combined into a single expression.

Civil Aeronautics Board Statistics and a methodology developed by United Research Inc. in 1962 (B-3) are used to develop frequency estimates. An informal survey of five airlines was taken to test the current validity of the United Research results. Appropriate changes were made.

The CAB/FAA statistics (B-2) reproduced below show that 2.5% of certificated route air carrier departures in CY 1980 were canceled at hub airports, 8.2% at non-hubs.

| <u>Hub Classification</u> | <u>Number of Hubs</u> | <u>CY 1980 Departures Scheduled</u> | <u>Scheduled Number</u> | <u>Completed* Percent</u> |
|---------------------------|-----------------------|-------------------------------------|-------------------------|---------------------------|
| Large | 25 | 2,905,923 | 2,840,474 | 97.7 |
| Medium | 41 | 1,058,438 | 1,031,238 | 97.4 |
| Small | 76 | 608,738 | 588,536 | 96.7 |
| Hubtotal | 142 | 4,573,099 | 4,460,248 | 97.5** |
| Non-hub | 486 | 606,383 | 557,165 | 91.8 |

*Excludes extra sections **Average percentage

United Research found that about 2/3 of air carrier cancellations, on an annual basis, were due to weather. They also found that air carrier diversions were about 1/6 as frequent as cancellations and that 5/6 of these diversions were caused by weather. The airline survey supported the United Research findings, except that the survey suggests the ratio of diversions to cancellations is closer to 1/10 than 1/6.

Weather-Caused Cancellations = 2.5% x 2/3
= 1.7% of all flights
Weather-Caused Diversions = 2.5% x 1/10 x 5/6
= 0.21% of all flights

Using data contained in a recent APO report, "Airfield and Airspace Capacity/Delay Policy Analysis," December 1981 - it is estimated that about 6.6% of all air carrier departures and about 13.2% of all air carrier arrivals were delayed 15 minutes or longer in 1980. Data collected by the FAA through its NASCOM program shows that of delays to IFR aircraft of over 30 minutes for the period 1971-80, an average of 29% were due to weather. Applying the NASCOM percentage to the APO delay data suggests that $13\% \text{ of flights} \times 29\% \text{ due to weather} = 3.8\% \text{ of all flights}$.

Recapitulating, for hub airports:

| | Large Air Carrier Airports | |
|--------------------------|-------------------------------|-----------------------|
| <u>Weather-Caused</u> | | <u>Normalized</u> |
| <u>Flight Disruption</u> | <u>Percent of All Flights</u> | <u>Distribution %</u> |
| Delays | 3.8 | 67 |
| Cancellations | 1.7 | 30 |
| Diversions | 0.2 | 3 |
| | 5.7 | 100 |

Given that in 1980, 8.2% of all air carrier flights into non-hub airports were canceled, estimates for the percentage of weather-caused cancellations, and diversions can be derived following the method used to estimate these rates for hub airports.

| | | |
|------------------------------|---|---------------------|
| Weather-Caused Cancellations | = | 8.2 x 2/3 |
| | = | 5.5% of all flights |
| Weather-Caused Diversions | = | 8.2 x 1/10 x 5/6 |
| | = | 0.7% of all flights |

Informal survey of several commuter air carriers revealed that 20-30% of the cancellations result from overflights. Choosing 25%, and applying it to the 5.5% cancellations, yields that overflights account for 1.4% of all flights, with 4.1% remaining as pure cancellations. The delay experience at non-hubs is similar to hubs.

We then have for non-hub airports:

| <u>Weather-Caused Flight Disruption</u> | <u>Non-hub Air Carrier Airports</u> | |
|---|-------------------------------------|--------------------------------------|
| | <u>Percent of All Flights</u> | <u>Normalized Distribution %</u> |
| Delays | 3.8 | 38 |
| Diversions | .7 | 7 |
| Cancellations | 4.1 | 41 |
| Overflights | 1.4 | 14 |
| | <u>10.0</u> | <u>100</u> |

G. Summary Air Carrier Flight Disruption Costs

Total estimated costs associated with weather-caused disruptions of air carrier flights can be determined by weighting the cost of each type of disruption by its proportional frequency of occurrence and then combining them into one equation. For each equation, each term was multiplied by the weight for that equation and a product obtained. Then, like variables were summed and then grouped similar to the original equations into a single equation which represents the average cost of air carrier flight disruptions. (This procedure was also followed in developing cost equations for the other user-categories). The individual equations, their respective weights, and the resulting average equations are summarized below.

Hub Airports:

| <u>Disruption</u> | <u>Cost Equation</u> | <u>Weight</u> |
|-------------------|--|---------------------|
| Delays | $(1.25 V_{PT})n + 0.32 AOC_1$ | 0.67 |
| Cancellation | $1.5 ((5 V_{PT} + V_{CLC} + .2 RPC)n - 1.083 AOC_1)$ | 0.30 |
| Diversions | $(4 V_{PT} + V_{DVC})n + 1.5 (AOC_1)$ | $\frac{0.03}{1.00}$ |

The average cost of air carrier flight disruptions at hub airports is thus estimated to be:

$$(3.21 V_{PT} + 0.03 V_{DVC} + 0.45 (V_{CLC} + .2 RPC))n - 0.24 AOC_1$$

Non-Hub Airports:

| <u>Disruption</u> | <u>Cost Equation</u> | <u>Weight</u> |
|-------------------|--|---------------------|
| Delays | $(.5 V_{PT})n + 0.19 AOC_2$ | 0.38 |
| Cancellation | $1.5 ((5 V_{PT} + V_{CLC} + .2 RPC)n - 0.413 AOC_2)$ | 0.41 |
| Diversions | $(6.5 V_{PT} + V_{DVC} + .5 (V_{CLC} + .2 RPC))n + 1.21 AOC_2$ | 0.07 |
| Overflights | $(9 V_{PT} + V_{DVC} + V_{CLC} + .2 RPC)n$ | $\frac{0.14}{1.00}$ |

The average cost of air carrier flight disruptions at non-hub airports is thus estimated to be:

$$(4.98 V_{PT} + 0.21 V_{DVC} + 0.79 (V_{CLC} + .2 RPC))n - 0.10 AOC_2$$

III. AIR TAXI FLIGHT DISRUPTIONS

Little data exist on the behavior of air taxi aircraft operators when faced with weather-caused flight disruptions. Air taxis were assumed to operate in much the same manner as the certificated route air carriers at non-hub airports, and the equations developed are similar. But because the aircraft are smaller and carry fewer passengers, different values are developed in section VII of this appendix for parameters in the equations.

A. Air Taxi Delay

A1. Costs proportional to aircraft hours: Air taxi delay were assumed the same as the non-hub air carriers (30 minutes total, 10 airborne, 20 ground but no 15 minutes of foregone slack time), but the percentage of operating costs represented by crew, as taken from reference B-5, was 39% for air taxis. Aircraft operating costs for weather delayed air taxi aircraft would then be:

For airborne delay: 0.17 hours x AOC₃
For ground delay : 0.33 hours x 0.39 x AOC₃
 Total delay : 0.30 AOC₃

where AOC₃ represents air taxi variable operating costs per airborne hour.

A2. Costs Associated With Passengers: Passenger delays were assumed identical to those for air carriers at non-hub airports (0.5 hours per passenger).

A3. Summary Air Taxi Delay Costs: The total cost per delayed air taxi aircraft is estimated to be:

$$(0.5 V_{PT})n + 0.30 AOC_3$$

where V_{PT} is the hourly value of passengers time and n is the number of passengers.

B. Air Taxi Cancellations, Diversions, and Overflights

Costs for air taxi cancellations, diversions, and overflights were estimated to be the same as air carriers at non-hubs, except for the adjustments noted below. All values for lost passenger time are taken as half that for air carrier, because as a rule, the number of passengers is smaller, the air taxi organization is smaller, and final decisions for how to handle diverted or canceled passengers will be made more quickly. Returning a passenger to his original destination is also less time consuming, since the stage lengths are shorter. For cancellations, another difference is the percentage of revenue recovery used in the flight cancellation scenario. United Research estimated 70% of air taxi passengers cancel their trips or use other means of travel when a flight is canceled. Finally, air taxis were presumed not to reimburse passengers for expenses when a flight was canceled due to poor weather conditions. For cancellations,

$$1.5 ((2.5 V_{PT} + .7 RPT)n - 0.413 AOC_3)$$

where RPT is the air taxi average revenue per passenger,

for diversions,

$$(3.0 V_{PT} + V_{DVT})n + .5(.7 RPT))n + 1.21 AOC_3$$

where V_{DVT} is the air taxi passenger handling expense for diverted passengers

for overflights,

$$(4.5 V_{PT} + V_{DVT} + .7 RPT)n$$

C. Air Taxi Summary

Air taxi flight disruption costs and the relative importance of each are summarized as follows:

| <u>Disruption</u> | <u>Cost Equation</u> | <u>Weight</u> |
|-------------------|--|---------------------|
| Delays | $(.5 V_{PT})n + 0.30 AOC_3$ | 0.38 |
| Cancellation | $1.5 ((2.5 V_{PT} + .7 RPT)n - 0.413 AOC_3)$ | 0.41 |
| Diversions | $(3 V_{PT} + V_{DVT})n + .5 (.7 RPT) + 1.21 AOC_3$ | 0.07 |
| Overflights | $(4.5 V_{PT} + V_{DVT} + .7 RPT)n$ | $\frac{0.14}{1.00}$ |

The average cost of an air taxi flight disruption becomes:

$$(2.57 V_{PT} + 0.21 V_{DVT} + 0.79 (.7 RPT))n - 0.06 AOC_3$$

IV. GENERAL AVIATION FLIGHT DISRUPTIONS

Most flight disruption impacts due to weather in general aviation is felt by business travelers flying in relatively large aircraft equipped for IFR operations. The pattern of flight disruptions experienced in general aviation probably is similar to that estimated for the air taxis, except that there are few secondary effects of flight disruptions in general aviation. The impact of flight disruptions on passengers is less because the aircraft they are traveling in is available for use as soon as the weather clears. Because of the greater number of airports that they can operate into, diversion times are less. Some interrupted trip expenses will be incurred for meals and overnight accommodations in some cases.

Additional flying operating costs (AOC_4), and interrupted trip expenses for canceled (V_{CLG}) and diverted (V_{DVG}) passengers represent the major cost impacts resulting from flight disruption to general aviation aircraft. There are few secondary effects of general aviation flight disruptions, and no distinction has been made between general aviation flight disruptions at hub and non-hub airports.

A. General Aviation Delay Costs

General aviation delay costs were assumed equal to air taxi delay costs. Cost proportional to aircraft hours is $0.30 AOC_4$, and the passenger delay is $.5 V_{PT}$, for a total of:

$$(0.5 V_{PT}) n + 0.30 AOC_4$$

B. General Aviation Cancellation Costs

When a general aviation aircraft is forced to cancel a flight due to poor weather no additional flying time, lost revenue, or passenger handling expense is involved. What remains from the air taxi equation is merely $2.5V_{PT}n$.

C. General Aviation Diversion Costs

The cost of a general aviation diversion is again similar to air taxi, but without the secondary effects. The equation is therefore:

$$(2.0 V_{PT} + V_{DVG})n + 1.5 AOC_4$$

D. General Aviation Summary Costs

General aviation flight disruption costs were weighted similar to air carriers at non-hub airports and air taxis, except that because overflights are not presumed to occur, the percentage for overflights has been added to cancellations. The summaries are therefore:

| <u>Disruption</u> | <u>Cost Equation</u> | <u>Weight</u> |
|-------------------|---------------------------------------|---------------|
| Delay | $(0.5 V_{PT})n + 0.30 AOC_4$ | 0.38 |
| Cancellation | $2.5 V_{PT} n$ | 0.55 |
| Diversion | $(2.0 V_{PT} + V_{DVG})n + 1.5 AOC_4$ | <u>0.07</u> |
| | | 1.00 |

The average cost of weather-caused general aviation disruption is

$$(1.71 V_{PT} + 0.07 V_{DVG})n + 0.22 AOC_4$$

V. MILITARY FLIGHT DISRUPTIONS

Military aircraft landing at civil airports fly non-commercially in a way that is very similar to general aviation. Losses or costs suffered would be in the form of passenger's lost time, and additional aircraft operating expense. For this analysis, the scenarios and equations for military aircraft were assumed identical to general aviation, except that the parameter values for aircraft operating expense developed in section VII of this appendix are higher. The summary equation is thus:

$$(1.71 V_{PT} + 0.07 V_{DVM})n + 0.22 AOC_5$$

VI. SUMMARY OF EQUATIONS

The following equations are reproduced from elsewhere in the text:

Air Carrier-

$$\text{Hubs: } (3.21 V_{PT} + 0.03 V_{DVC} + 0.45 (V_{CLC} + .2 \text{ RPC}))n - 0.24 \text{ AOC}_1$$

$$\text{Non-hubs: } (4.98 V_{PT} + 0.21 V_{DVC} + 0.79 (V_{CLC} + .2 \text{ RPC}))n - 0.10 \text{ AOC}_2$$

$$\text{Air Taxi: } (2.57 V_{PT} + 0.21 V_{DVT} + 0.79 (.7 \text{ RPT}))n - 0.06 \text{ AOC}_3$$

$$\text{General Aviation: } (1.71 V_{PT} + 0.07 V_{DVG})n + 0.22 \text{ AOC}_4$$

$$\text{Military: } (1.71 V_{PT} + 0.07 V_{DVM})n + 0.22 \text{ AOC}_5$$

VII. Value of Variables

Weather caused flight disruption costs have been estimated in general terms in this appendix. This is to allow for the number of passengers and fleet mix that would apply to the various user categories to vary. That is, over time the generalized form of these equations would permit easy entry of new values for the variables as the values change and are updated.

Specific costs can be estimated by substituting the appropriate value in place of the symbols and then deriving the solution. The following values, taken from the sources as shown, were current and expressed in 1981 dollars at this writing:

| | | |
|----------------|---|--|
| V_{PT} | = | hourly value of passengers time, \$19.00 (Reference B-5) |
| n | = | number of deplaning passengers, for air carriers at hub airports, 61.4, at non-hub airports, 16.1 (Source, reference B-2); for air taxi, 5.1; for general aviation, 3.2; for military, 5.6. (Source, reference B-10) |
| AOC_1 | = | aircraft variable operating costs per airborne hour at hub airports, \$1764 |
| AOC_2 | = | aircraft variable operating costs per airborne hour at non-hub airports, \$1644 |
| AOC_3 | = | air taxi variable operating cost per airborne hour, \$239 |
| AOC_4 | = | general aviation variable operating cost per airborne hour, \$154 |
| AOC_5 | = | military variable operating cost per airborne hour, \$1025 |

V_{CLC} = air carrier passenger handling expense for canceled passengers, \$43; includes overnight lodging (Source, reference B-11)

V_{DVC} = air carrier passenger handling expense for diverted passengers, \$63; includes overnight lodging, meals, and transportation to original destination (\$20) (Source, reference B-11 and conversations with four airlines)

V_{DVT} = air taxi passenger handling expense for diverted passengers, \$53; includes \$43 for overnight lodging, \$10 for transportation to original destination. (Source, same as above)

V_{DVG} = general aviation passenger handling expense for diverted passengers, \$53; includes \$43 for overnight lodging, \$10 for transportation to original destination. (Source, same as above)

V_{DVM} = military passenger handling expense for diverted passengers, \$53 (same as general aviation)

RPC = air carrier average revenue per passenger, \$98; domestic trip lengths average about 750 miles, and the cost per passenger mile for tickets is 13 cents. (Source, FAA APO-110)

RPT = air taxi average revenue per passenger, \$19; domestic trip lengths average about 110 miles, and the cost per passenger mile for tickets is 17.5 cents. (Source, FAA APO-110)

VIII. VALUES OF DISRUPTIONS

Applying the values in section VII, to the equations in Section VI, yields the following disruption costs:

| | |
|---------------------|--------|
| Air Carrier Hub: | \$5167 |
| Air Carrier Non-hub | \$2370 |
| Air Taxi | \$346 |
| General Aviation | \$154 |
| Military | \$428 |

REFERENCES FOR APPENDIX B

- B-1 Establishment Criteria for Category I Instrument Landing System (ILS), Report No. ASP-75-1, Office of Aviation System Plans, FAA, DOT, December 1975.
- B-2 Airport Activity Statistics of the Certificated Route Air Carriers, 12 Months Ended December 31, 1980 Prepared jointly by CAB and FAA DOT, Washington, D.C.
- B-3 Fromm, G., "Economic Criteria for Federal Aviation Agency Expenditures," United Research Inc., Cambridge, Massachusetts, June 1962.
- B-4 Civil Aeronautics Board's Bureau of Accounts and Statistics. Report form 438 "on Time Performance" of trunk air carriers, monthly, Washington, D.C.
- B-5 Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs. Report No. FAA-APO-81-3, Office of Aviation Policy and Plans, September, 1981.
- B-6 Air Carrier Traffic Statistics, CAB, July 1979.
- B-7 Aircraft Utilization and Propulsion Report, FAA, Oklahoma City, Oklahoma, January 1976.
- B-8 Airfield and Airspace Capacity/Delay Policy Analysis, Office of Aviation Policy and Plans, FAA, DOT, November 1981
- B-9 Official Airline Guide, Sept. 1981.
- B-10 Investment Criteria for Airport Surveillance Radar, Report No. FAA-APO-81-13, Office of Aviation Policy and Plans, November, 1981.
- B-11 Travel Market Yearbook, 1981

APPENDIX C

ESTIMATION OF ANNUAL INSTRUMENT APPROACHES

1. Introduction

This appendix describes how instrument approach counts can be estimated from counts of total operations. The method is useful in the absence of counts, or to evaluate suspected counts. It is based on the number of operations, weather probabilities, the percentage of pilots equipped to make an instrument approach, and some assumptions about local versus itinerant operations. The method was developed by Systems Control, Inc. (SCI) and reported in Preliminary Analysis of the Correlation Between Annual Instrument Approaches, Operations and Weather, (Federal Aviation Administration, Report No. DOT-FA-78WA-4175, December 1980) (Reference C-1). A more complete discussion than is possible in this appendix may be found in that report.

2. The model

The models are conceptually simple. The number of arrivals in all kinds of weather is apportioned according to the percentage of instrument and visual weather. Then, because there is more flight activity in good weather, the result is adjusted downward by a constant whose value depends on the class of operation - air carrier, air taxi, or general aviation.

SCI obtained instrument approach counts and total operations counts at several locations where good statistics were available. They used that data in a regression model to find an estimate for the fraction of each class. The resulting equations are, for air carrier, air taxi, and general aviation, respectively,

instrument approaches =

$$\frac{\text{air carrier operations}}{2} \times \text{PIFR} \times .87$$

$$\frac{\text{air taxi operations}}{2} \times (\text{PIFR} - \text{PC}) \times (1 - R_{at}) \times .93$$

$$\frac{\text{GA itinerant operations}}{2} \times (\text{PIFR} - \text{PC}) \times (.8 - .5R_{ga})$$

where,

PIFR = probability of weather with either ceiling less than 1500 feet or visibility less than 3 miles

1

PC = probability of weather below IFR minima, for the existing instrument approach which has the lowest minima. Minima are selected from the approach charts using approach category B for air taxi, and category A for general aviation.

Rat = ratio of air taxi operations to total operations.

Rga = ratio of general aviation itinerant operations to total operations.

Each of the above equations contains an operations count, which is the independent variable from which the instrument approach count is derived. Since operations are the sum of takeoffs and landings, the operations counts are in every case divided by two. In the general aviation category, SCI obtained better results from their equation if local operations were excluded. (Local operations are aircraft operating in the local traffic pattern, or those known to be departing for or arriving from, flight in local practice areas located within a 20 mile radius of the airport. Local operations include simulated instrument approaches or low passes at the airport.)

There is a term in each of the equations which adjusts for the site-specific percentage of time that weather is less than visual minima. The form of the equation is different among the activity classes, and was selected to best fit the observed data.

The final term adjusts for errors in the too-simple assumption that the proportion of total approaches which are instrument, is the same as the proportion of total time when there is instrument weather. The assumption would be true if all aircraft, airmen, and airports were suitably equipped for instrument landings, and if pilots were never dissuaded by bad weather. In fact, not all pilots, planes, and airports can handle instrument weather, and flights on more casual missions are likely to stay on the ground in bad weather.

The general aviation and air taxi equations contain an additional refinement. SCI noted that GA airports with substantial air carrier activity tended to have a greater proportion of GA and air taxi flyers unaffected by bad weather. In other words, a GA pilot whose destination is a major air carrier airport will be more likely to make an instrument approach, than to cancel his flight and stay home.

The precise form of each of the above equations was arrived at through regression analysis: the form which produced the best predictor of the results was selected.

3. Obtaining weather percentages.

The equation depends directly on the percentage of time the weather is less than particular approach minima. These percentages may be obtained as

shown in Appendix D, which presents data for Muskegon, Michigan, as an example. Ceiling and visibility condition (2) represents the percentage of time the ceiling is less than 1500 feet and/or the visibility is less than 3 miles, the number which is required for PIFR. For Muskegon, that number (for all times) is 16.7% (0.167).

The number for PC is the percentage of time the weather is below minima for the IFR approach which has the lowest minima. For Muskegon, the 29 October 1981 edition of U. S. Instrument Approach Procedures (Reference C-2) shows that the lowest minima are for an ILS approach to runway 32. The minima are listed by category determined by approach speed, and are identical for categories A and B, at 300-3/4. Appendix D develops as 2.15 the percentage of time the weather is less than 300-3/4, which is the value for PC.

When a particular site is not reported in reference C-2, values from a nearby airport may be used, or values for nearby airports may be averaged.

4. How the model is applied

To use the model, apply the equations shown. The terminal area operations counts are available from the FAA terminal area forecast. The lowest IFR minima for the airport can be obtained from U. S. Instrument Approach Procedures (Reference C-2).

Muskegon airport provides an example. Figure C-1, developed from the 1980 terminal area forecast shows total operations counts of 9779 for air carrier, air taxi, and itinerant GA as 7000, 1000, and 38,000, respectively. Total operations were 97,000. From the example in section 3, weather is less than 1500/3 for .167 of the time. The ratio of GA itinerant operations to total operations (R_{ga}) is 38/97, and of air taxi to total operations (R_{at}) is 1/97. PC is .0215. The instrument approach counts, determined from the formulas for air carrier, air taxi, GA, are thus 508, 6, and 1670, respectively.

Figure C-1

Reference for Appendix C

- C-1. Preliminary Analysis of the Correlation Between Annual Instrument Approaches, Operations and Weather, (Federal Aviation Administration, Report No. DOT-FA-78WA-4175, December 1980).
- C-2. U.S. Instrument Approach Procedures, October 1981.

APPENDIX D

USING WEATHER DATA TO EVALUATE BENEFIT OF REDUCED MINIMA

1. Introduction

This appendix describes a method for determining the percentage of increased activity which result from lowered landing minima, such as those made possible by an electronic landing aid. The assumption behind the method is that when landing minima are lower — that is, when aircraft can complete landings in poorer weather than before — the airport will be open a greater percentage of the time.

A simple example will best express the assumption. It is first assumed that an airport experiences weather during which instrument approaches are necessary thirty days per year; further, that on ten of those days, the weather is below instrument minima. The instrument approaches which thus have been made at the airport are made on 20 days out of the year. If the landing minima are lowered so that on two more of the 30 days, the weather are above the new landing minima, the airport is then open to instrument approaches 22 days out of the year, or 10% more than it had been. If 1000 aircraft had made instrument approaches on the 20 days under the old minima, the key assumption is that 10% more aircraft, or 1100, could now land if the minima were lowered.

This appendix tells how to determine the relevant percentage, both on a national average basis, and for a specific site.

2. Sources of Data

Summaries of weather records have been made for the FAA by the National Climatic Center at Asheville, North Carolina. Each of the summaries states what percentage of the time the weather at a specific site will be less than certain combinations of ceiling and visibility. There are three such publications which may be consulted:

1. A 1964 report (reference D-1) shows, for 32 North American airports, percentages of time the weather is less than ceilings of 100, 200, 300, 400, 500, 600, 800, 1000, 1500, 2000, 3000, and visibilities of 1/16, 1/8, 1/4, 1/2, 3/4, 1, 1-1/2, and 3 miles. The publication is very detailed by breakdowns of ceiling and visibility, but reports on only 32 airports.
2. A total of 271 airports are included in the percentages of hourly weather observations falling within six ceiling-visibility categories (reference D-2). Those categories are (showing ceiling-visibility): greater than 1500-3, less than 1500-3, less than 1500-3 but greater or equal to 400-1, less than 400-1 but greater or equal to 200-1/2, less than 200-1/2, but greater or equal to 100-1/4, and less than 100-1/4. Compared to the first source, there is thus less detail on specific ceilings and visibilities, but more sites.

3. A total of 283 airports are reported on in 19 volumes (reference D-3). The volumes use the same six categories as reference D-2, but report by wind direction as well.

3. Increased Aircraft Activity Resulting from Lowered Minima

Any of the publications may be used, as appropriate. If the specific airport is not listed in any of the publications, a nearby airport, an average of nearby airports, or a national average may be used.

Computation of the number of additional instrument approaches made possible by the landing aid involves the following three steps: First, the percentage of time the airport is not VFR but open under current minima must be determined. Then, the additional percentage of time the airport would be open with the proposed improvement is determined. Finally, the ratio of the two percentages, gives the percentage of additional instrument approaches which could be completed with the proposed improvement. Figure D-1 shows the listing from reference D-2 for Muskegon, Michigan.

| STATION#14840 MUSKEGON, MICHIGAN | | | | | | | | PERIOD OF RECORD 01/48-12/52; 01/60-12/64 | | | |
|----------------------------------|--------------|-----------------------------------|------|------|-----|-----|-----|--|------|------|------|
| MOOR GROUP | NO.OF OBS | CEILING-VISIBILITY CATEGORIES (%) | | | | | | SYSTEM ENHANCEMENT FACTORS (%) | | | |
| | | (1) | (2) | (3) | (4) | (5) | (6) | VOR | CAT1 | CAT2 | MIN* |
| JAN ALL | 7440 | 63.7 | 36.3 | 29.8 | 3.9 | 1.1 | 1.3 | 82.2 | 10.6 | 3.1 | 4.1 |
| FEB " | 6809 | 73.5 | 26.5 | 22.6 | 2.5 | 0.7 | 0.7 | 85.3 | 9.4 | 2.7 | 2.6 |
| MAR " | 7440 | 78.1 | 21.9 | 17.6 | 2.8 | 0.7 | 0.8 | 80.4 | 12.9 | 3.1 | 3.6 |
| APR " | 7200 | 85.2 | 14.8 | 12.4 | 1.4 | 0.4 | 0.6 | 84.2 | 9.5 | 2.5 | 3.8 |
| MAY " | 7440 | 91.3 | 8.7 | 6.3 | 1.3 | 0.4 | 0.7 | 72.3 | 14.8 | 4.8 | 8.2 |
| JUN " | 7200 | 93.8 | 6.2 | 4.7 | 0.7 | 0.3 | 0.4 | 76.5 | 11.9 | 5.4 | 6.3 |
| JUL " | 7440 | 93.4 | 6.6 | 5.2 | 0.7 | 0.1 | 0.5 | 79.4 | 11.2 | 2.2 | 7.1 |
| AUG " | 7439 | 91.5 | 8.5 | 6.6 | 1.0 | 0.4 | 0.5 | 78.2 | 11.6 | 4.5 | 5.7 |
| SEP " | 7198 | 91.2 | 8.8 | 7.7 | 0.8 | 0.2 | 0.1 | 87.3 | 8.7 | 2.4 | 1.6 |
| OCT " | 7440 | 87.9 | 12.1 | 8.5 | 1.2 | 0.8 | 1.6 | 70.7 | 9.6 | 6.3 | 13.3 |
| NOV " | 7200 | 80.2 | 19.8 | 16.0 | 1.7 | 0.7 | 1.4 | 80.7 | 8.6 | 3.5 | 7.2 |
| DEC " | 7439 | 69.7 | 30.3 | 24.9 | 3.6 | 1.0 | 0.8 | 82.1 | 11.9 | 3.4 | 2.6 |
| ANN 07-13 | 25578 | 80.6 | 19.4 | 16.1 | 2.0 | 0.6 | 0.7 | 83.0 | 10.4 | 2.9 | 3.7 |
| 14-21 | 29229 | 86.3 | 13.7 | 11.8 | 1.3 | 0.3 | 0.4 | 85.6 | 9.4 | 2.4 | 2.6 |
| 22-06 | 32878 | 82.8 | 17.2 | 13.1 | 2.1 | 0.8 | 1.3 | 76.0 | 12.1 | 4.6 | 7.3 |
| ALL | 87685 | 83.3 | 16.7 | 13.5 | 1.8 | 0.6 | 0.8 | 81.0 | 10.8 | 3.4 | 4.8 |

CEILING VISIBILITY CONDITIONS (% OF TOTAL OBSERVATIONS)

SYSTEMS ENHANCEMENT FACTORS
(CEILING VISIBILITY CONDITIONS)

(1) ≥ 1500 FEET AND 3 MILES

(2) < 1500 FEET AND/OR 3 MILES

(3) < 1500 FEET AND/OR 3 MILES, BUT ≥ 400 FEET AND 1 MILE

(4) < 400 FEET AND/OR 1 MILE, BUT ≥ 200 FEET AND 1/2 MILE

(5) < 200 FEET AND/OR 1/2 MILE, BUT ≥ 100 FEET AND 1/4 MILE

(6) < 100 FEET AND/OR 1/4 MILE

VOR=FREQ (3)/FREQ(2)

CAT1 ILS=FREQ(4)/FREQ(2)

CAT2 ILS=FREQ(5)/FREQ(2)

*BELOW MINIMUMS=FREQ(6)/FREQ(2)

Figure D-1

Step 1

To determine the percentage of time the airport is below VFR but open under current minima, find the minima for the instrument approach which yields the lowest minima for the largest aircraft type utilizing the candidate airport. For the purposes of example, assume that these minima were 400-1. From Figure D-1, the time the weather is less than 400-1 is the sums of columns (4), (5), and (6), or 3.2% (0.032).

Ceiling and visibility condition (2) represents the percentage of time the weather is ceiling less than 1500 feet and/or visibility less than 3 miles, the minima which are used in deciding whether to count an instrument approach for the pilot who flies the procedure. For Muskegon, that number (for all times) is 16.7% (0.167).

The difference between these two numbers, 0.135, is the result of step one, the percentage of time the airport is not VFR but open under current minima.

Step 2

If an improvement were to be made which lowered the minima to 200-1/2, the airport would be open an additional percentage of time. Ceiling and visibility condition (4) is the percentage of time between 400-1 and 200-1/2, which for Muskegon is 1.8% (0.018).

Step 3

The ratio of the result of steps 1 and 2 is $0.018/0.135$, or 0.133. This is the proportion of current instrument approaches which could additionally be completed with the improvement. If 1000 approaches were completed previously, 133 more would be expected.

4. Interpolating for Values Outside Those in the References

Reference D-1 contains detailed data for 32 airports, and the detail is sufficient to obtain any necessary lowered minima percentages directly. But the 32 airports are major ones, and there are hundreds of others which may be considered for improvements but are shown only in references D-2 or D-3. For those, the detail in reference D-1 may be used to interpolate among the values in the other publications. Table D-1 is averages of percentages of weather conditions at the 32 airports.

Table D-1

| Ceiling (feet) | Visibility (miles) | | | | | | | |
|-------------------|--------------------|-------|-------|-------|-------|-------|-------|-------|
| | 1/16 | 1/8 | 1/4 | 1/2 | 3/4 | 1 | 1-1/2 | 3 |
| 100 | 0.34 | 0.43 | 0.65 | 0.99 | 1.43 | 1.95 | 3.10 | 7.09 |
| 200 | 0.71 | 0.76 | 0.89 | 1.12 | 1.52 | 2.02 | 3.14 | 7.10 |
| 300 | 1.21 | 1.24 | 1.34 | 1.48 | 1.79 | 2.22 | 3.26 | 7.13 |
| 400 | 1.89 | 1.92 | 2.00 | 2.13 | 2.37 | 2.72 | 3.63 | 7.29 |
| 500 | 2.67 | 2.69 | 2.77 | 2.88 | 3.09 | 3.39 | 4.20 | 7.61 |
| 600 | 3.46 | 3.49 | 3.56 | 3.67 | 3.84 | 4.10 | 4.82 | 7.99 |
| 800 | 5.26 | 5.29 | 5.36 | 5.46 | 5.60 | 5.81 | 6.40 | 9.15 |
| 1,000 | 7.04 | 7.07 | 7.14 | 7.24 | 7.36 | 7.54 | 8.05 | 10.48 |
| 1,500 | 10.63 | 10.66 | 10.73 | 10.82 | 10.92 | 11.06 | 11.47 | 13.50 |
| 2,000 | 13.33 | 13.35 | 13.42 | 13.51 | 13.60 | 13.74 | 14.09 | 15.92 |
| 3,000 | 17.90 | 17.93 | 18.00 | 18.08 | 18.18 | 18.29 | 18.60 | 20.22 |

A National Average Percent of Weather Observations with ceilings or visibilities less than selected values. Example: 1.79% of the time, the ceiling is less than 300 feet, or the visibility is less than 3/4 mile (or both).

As an example of the kind of interpolation which is possible, assume that the weather minima for which a percentage is required is 300-3/4. The interpolation ratio is thus,

$$\frac{(\text{local } \% \text{ for } 300-3/4 - 200-1/2)}{(\text{local } \% \text{ between } 400-1 \text{ \& } 200-1/2)} = \frac{(\text{ntl } \% \text{ } 300-3/4 - \text{ntl } \% \text{ } 200-1/2)}{(\text{ntl } \% \text{ for } 400-1 - \text{ntl } \% \text{ for } 200-1/2)}$$

At Muskegon,

$$\frac{(\text{local } \% \text{ for } 300-3/4 - 200-1/2)}{1.8} = \frac{0.67}{1.60}$$

The number in the parentheses is obtained by calculating,

$$\frac{1.8 \times 0.67}{1.60}$$

or 0.75%, which is the additional percentage of time the airport would be open after an improvement which lowered the minima from 300-3/4 to 200-1/2.

To determine the percentage of time the airport is below VFR but open for minima of 300-3/4, the percentage determined above (time between 300-3/4 and 200-1/2), is added to the sum of columns (5) and (6) (time less than 200-1/2), or $0.75 + 0.6 + 0.8 = 2.15\%$, which is the time weather is less than 300-3/4. This number is then subtracted from column (2) to yield $16.7 - 2.15 = 14.55$, which is then the percentage of time the airport is below VFR but open for minima of 300-3/4.

Table D-2 gives the average increases in airport utilization associated with reductions from specified nonprecision approach minima to MLS minima (200-1). For example, if an MLS permitted a reduction in minima of from 400-1 to 200-1/2, an average 14.8 percent increase in runway utilization would be expected.

TABLE D-2

Average Increases in Airport Utilization Associated With
Reductions in Approach Minima from Specified Values
to MLS Minima (200 feet and/or 1/2 mile)

| Ceiling (Feet) | Visibility (Miles) | | | | |
|----------------|--------------------|------------|----------|--------------|----------|
| | <u>1/2</u> | <u>3/4</u> | <u>1</u> | <u>1-1/2</u> | <u>3</u> |
| | % | % | % | % | % |
| 200 | 0 | 3.3 | 7.8 | 19.5 | 93.4 |
| 300 | 3.0 | 5.7 | 9.8 | 20.9 | 94.3 |
| 400 | 8.9 | 11.2 | 14.8 | 25.4 | 99.4 |
| 500 | 16.6 | 18.9 | 22.5 | 33.1 | 110.2 |
| 600 | 25.9 | 28.2 | 31.7 | 42.6 | 124.7 |
| 800 | 54.0 | 56.7 | 61.0 | 74.4 | 184.6 |
| 1,000 | 97.8 | 102.0 | 107.7 | 127.2 | 309.9 |
| 1,500 | 361.9 | 379.8 | 407.4 | 509.9 | - |

5. Runway Utilization

The utilization of an airport runway is important for computing the benefits of a runway specific landing minima improvement. If, for example, the improvement is placed on a runway which is usable only half of the time because of crosswinds or tailwinds, the number of aircraft approaching in instrument conditions which can avoid flight disruptions by using that runway is fewer.

Some airports have traffic counts available by runway, but almost always the counts are accumulated over all weather conditions. What is really of interest is the proportion of time the runway could be used when the weather conditions are within range of the landing minima afforded by the improvement. For example, an instrument landing system is most useful when the weather is less than non-precision approach minima, or at relatively low ceilings and/or visibilities. The strongest

winds do not occur with the lowest ceilings, so that the likelihood that the MLS approach cannot be used because of cross or tail winds is relatively small.

Reference D-3 reports ranges of ceiling and visibility by wind direction and speed, so that an approximation of runway usability can be derived on a site specific basis. Figures D-2 and D-3 are taken from the reference for Muskegon, MI. Suppose, that an improvement is planned for runway 32. Assume that all flights could use runway 32 when the wind is between 0-3 knots. That occurs 10.2% of the time. Then, assume that flights arriving with windspeeds of 4-12 knots could use runway 32 when wind directions were within 90 degrees of the runway, that is, NE through SW via NW. That occurs 22.5% of the time. Then, assume that flights arriving with higher windspeeds could use runway 32 when the wind was within 45 degrees of the runway, that is, N through W. That occurs 14.5% of the time. The total utilization for runway 32 during the day is therefore 47.2%. A similar procedure for the night chart yields a value of 50.9%, for a day and night average of 49.1%.

Computations in the paragraph above, assumed that no other runway achieves the minima afforded by the proposed improvement. If the improvement would reduce minima for a second runway to a level already available with another runway, the percentage of utilization is correspondingly less. If, in the example above, an improvement of this kind were planned for runway 32 with equivalent minima already available on runway 14, runway 14 could be used for all wind directions when wind speeds were 3 knots or less, and for directions of NE and SW when winds were 4-12 MPH. The day utilization is therefore 47.2 less 10.2 less 1.8 less 4.1, or , or 31.1%

Although values for specific airports may be determined in this way, an estimate of a national average of utilization for the first and second instrumented runways is useful in a national screening criteria. To approximate this value, a sample of 21 airports was drawn from reference D-3. Computations identical to those in the above paragraphs were carried out, and percentages of utilization of 70% and 25% were determined. Utilization percentages for installation on more than two runways of devices achieving identical minima were not determined for use in the screening criteria. Three systems -- for precision landings, for example, are almost never installed for purposes of lowered minima and airport utilization, but instead, for reasons of traffic flow, such as on a parallel runway. Benefit of enhanced traffic flow is outside the scope of this analysis.

CEILING-VISIBILITY WIND TABULATIONS

ANNUAL

STATION NAME: MKG MUSKEGON, MI

PERIOD: 1948-1978

CLASS 4 / DAY

STATION NUMBER: 14840

NO. OBS.: 684

| D I R | SPEED GROUPS (MPH) | | | | | | | | | | | | | | AVG WIND SPEED |
|-------------|--------------------|------|------|------|-------|------|-------|------|-------|-----|-------|-----|-----|----|----------------------|
| | 0-3 | | 4-12 | | 13-15 | | 16-18 | | 19-24 | | 25-31 | | 32+ | | TOTAL |
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | |
| N | .0 | .1 | .0 | 2.0 | .0 | .0 | .0 | 1.0 | .0 | .0 | .0 | .0 | .0 | .0 | .1 3.8 |
| NNE | .0 | .4 | .0 | 1.2 | .0 | .3 | .0 | .1 | .0 | .0 | .0 | .0 | .0 | .0 | .0 2.0 |
| N E | .0 | .4 | .0 | 1.8 | .0 | .3 | .0 | .3 | .0 | .1 | .0 | .1 | .0 | .0 | .1 3.1 |
| ENE | .0 | .0 | .1 | 3.9 | .0 | .3 | .0 | .4 | .0 | .3 | .0 | .0 | .0 | .0 | .1 5.0 |
| E | .0 | 1.0 | .1 | 6.1 | .0 | .9 | .0 | .7 | .0 | .7 | .0 | .3 | .0 | .0 | .2 9.8 |
| ESE | .0 | .3 | .1 | 4.7 | .0 | 1.8 | .0 | .9 | .0 | .1 | .0 | .0 | .0 | .0 | .1 7.7 |
| SE | .0 | .6 | .1 | 7.0 | .0 | .4 | .0 | .3 | .0 | .0 | .0 | .0 | .0 | .0 | .2 8.3 |
| SSE | .0 | .4 | .1 | 3.2 | .0 | .9 | .0 | .9 | .0 | .1 | .0 | .0 | .0 | .0 | .1 5.6 |
| S | .0 | .6 | .0 | 2.3 | .0 | .6 | .0 | .9 | .0 | .4 | .0 | .0 | .0 | .0 | .1 4.8 |
| SSH | .0 | .0 | .1 | 3.5 | .0 | 1.8 | .0 | .7 | .0 | 1.0 | .0 | .1 | .0 | .1 | .1 7.3 |
| SW | .0 | .7 | .1 | 4.1 | .0 | 1.3 | .0 | 1.3 | .0 | .6 | .0 | .3 | .0 | .1 | .2 8.5 |
| WSW | .0 | .1 | .0 | 2.5 | .0 | .4 | .0 | .7 | .0 | .7 | .0 | .3 | .0 | .0 | .1 4.8 |
| W | .0 | 1.0 | .1 | 3.4 | .0 | 1.2 | .0 | 1.6 | .0 | 1.2 | .0 | .0 | .0 | .0 | .2 8.3 |
| WNW | .0 | .3 | .1 | 3.2 | .0 | .4 | .0 | 1.0 | .0 | 1.8 | .0 | .1 | .0 | .0 | .1 6.9 |
| NW | .0 | .4 | .0 | 2.5 | .0 | 1.2 | .0 | .4 | .0 | 1.6 | .0 | .3 | .0 | .1 | .1 6.6 |
| NNW | .0 | .3 | .0 | 1.8 | .0 | .3 | .0 | .7 | .0 | .4 | .0 | .6 | .0 | .0 | .1 4.1 |
| CALM | .1 | 3.4 | | | | | | | | | | | | | .1 3.4 |
| TOTAL | .2 | 10.2 | 1.0 | 53.2 | .2 | 12.0 | .2 | 12.1 | .2 | 9.8 | .0 | 2.2 | .0 | .4 | 1.8 100 11.2 |

Figure D-2

CEILING-VISIBILITY WIND TABULATIONS

ANNUAL

STATION NAME: MKG MUSKEGON, MI

PERIOD: 1948-1978

CLASS 4 / NIGHT

STATION NUMBER: 14840

NO. OBS.: 703

| D I R | SPEED GROUPS (MPH) | | | | | | | | | | | | | | AVG WIND SPEED | | |
|-------------|--------------------|------|------|------|-------|------|-------|-----|-------|-----|-------|-----|-----|----|----------------------|-------|------|
| | 0-3 | | 4-12 | | 13-15 | | 16-18 | | 19-24 | | 25-31 | | 32+ | | | TOTAL | |
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | | | C |
| N | .0 | .6 | .0 | 2.1 | .0 | .6 | .0 | .3 | .0 | .3 | .0 | .1 | .0 | .0 | .1 | 4.0 | 9.9 |
| NNE | .0 | .3 | .0 | 1.3 | .0 | .1 | .0 | .3 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | 2.0 | 8.4 |
| N E | .0 | 1.1 | .0 | 2.1 | .0 | .3 | .0 | .1 | .0 | .0 | .0 | .1 | .0 | .0 | .1 | 3.8 | 7.3 |
| ENE | .0 | .7 | .1 | 3.4 | .0 | .7 | .0 | .3 | .0 | .0 | .0 | .0 | .0 | .0 | .1 | 5.1 | 8.9 |
| E | .0 | .6 | .1 | 6.8 | .0 | .9 | .0 | .9 | .0 | .4 | .0 | .0 | .0 | .0 | .2 | 9.5 | 9.3 |
| ESE | .0 | .9 | .1 | 7.0 | .0 | 1.3 | .0 | .4 | .0 | .4 | .0 | .0 | .0 | .0 | .2 | 10.0 | 9.6 |
| SE | .0 | 1.1 | .1 | 4.4 | .0 | .7 | .0 | .4 | .0 | .0 | .0 | .0 | .0 | .0 | .1 | 6.7 | 8.1 |
| SSE | .0 | .3 | .1 | 2.6 | .0 | .7 | .0 | .6 | .0 | .0 | .0 | .0 | .0 | .0 | .1 | 4.1 | 10.4 |
| S | .0 | .4 | .0 | 2.0 | .0 | 1.4 | .0 | .9 | .0 | .4 | .0 | .1 | .0 | .0 | .1 | 5.3 | 12.2 |
| SSW | .0 | .3 | .1 | 2.6 | .0 | 1.7 | .0 | .9 | .0 | 1.1 | .0 | .1 | .0 | .0 | .1 | 6.7 | 13.6 |
| SW | .0 | .6 | .1 | 3.1 | .0 | 1.0 | .0 | .6 | .0 | 1.3 | .0 | .0 | .0 | .0 | .1 | 6.5 | 11.7 |
| WSW | .0 | .3 | .1 | 3.3 | .0 | .9 | .0 | .4 | .0 | .9 | .0 | .0 | .0 | .0 | .1 | 5.7 | 11.9 |
| W | .0 | .1 | .1 | 3.0 | .0 | 1.3 | .0 | .9 | .0 | 1.0 | .0 | .3 | .0 | .0 | .1 | 6.5 | 13.3 |
| WNW | .0 | .4 | .1 | 3.3 | .0 | .4 | .0 | .7 | .0 | 1.7 | .0 | .3 | .0 | .1 | .1 | 7.0 | 13.9 |
| NW | .0 | .7 | .0 | 2.0 | .0 | .7 | .0 | .3 | .0 | 1.1 | .0 | .9 | .0 | .0 | .1 | 5.7 | 14.4 |
| NNW | .0 | .0 | .1 | 2.6 | .0 | 1.1 | .0 | .6 | .0 | .6 | .0 | .1 | .0 | .0 | .1 | 5.0 | 13.0 |
| CALM | .1 | 6.4 | | | | | | | | | | | | | .1 | 6.4 | |
| TOTAL | .3 | 14.8 | 1.1 | 51.5 | .3 | 13.8 | .2 | 8.4 | .2 | 9.2 | .0 | 2.1 | .0 | .1 | .2 | 100 | 10.4 |

Figure D-3

REFERENCES FOR APPENDIX D

- D-1. Climatic Studies for Proposed Landing Systems, Volumes 1-32,
Federal Aviation Administration Report No. RD-64-54, June 1964.
- D-2. Ceiling-Visibility Climatological Study and Systems Enhancement
Factors, Federal Aviation Administration Report No.
DOT-FA75WAI-547, June 1975.
- D-3. Wind-Ceiling-Visibility Data at Selected Airports, Volumes 1-11,
National Climatic Center, Asheville, North Carolina, April 1981.

Appendix E

Critical Values

The Federal Aviation Administration (FAA) uses certain economic values in the evaluation of investment and regulatory programs. These values, commonly referred to as "critical values," provide the bases upon which the effectiveness of the aviation system may be denominated and assessed in monetary terms. The critical values used in this report include the value of time of air travelers, the value of a statistical life, unit costs of statistical aviation injuries, unit replacement and restoration costs of damaged aircraft and aircraft variable operating costs. These values are summarized in Figure E-1. A complete discussion of why these values are used in FAA's economic analyses is given in Reference E-11.

Other figures included with precision landing system critical values are average numbers of occupants and passengers per aircraft. Occupant figures, used to calculate safety benefits, include crew; passenger figures, used to calculate averted flight disruption benefits, exclude crew for air carriers and air taxis since the value of the crew's time is included in the variable operating costs as salary and wages.

Reference E-6 reports replacement/restoration costs and variable operating costs for nine categories of air carrier aircraft, including average values for the entire air carrier fleet. Ideally, if the regional offices can furnish fleet information, the need to use any estimates based on national or any other averages can be eliminated or at least reduced. Without site specific data, however, values based on the average experience must be substituted and used to estimate the critical values. National fleet information was used to develop the critical values in Tables E-2 and E-3. It is recommended that these values be used if site-specific data are unavailable.

Figure E-1

Summary of Critical Values Used in Precision Landing System Criteria (\$ 1981)

| | | | | |
|--|------------------|-----------|-----------|------------|
| Fatality, Serious Injury, Minor Injury (\$K) | 580.00 | 42.00 | 16.00 | |
| Passenger Time (\$ Per Hour) | 19.00 | | | |
| | <u>AC</u> | <u>AT</u> | <u>GA</u> | <u>MIL</u> |
| Destroyed Aircraft Replacement Costs (\$K) | Hub 5,644.60 | 281.80 | 277.60 | 2,472.00 |
| | Non-Hub 4,481.30 | | | |
| Damaged Aircraft Restoration Costs (\$K) | Hub 1,881.50 | 93.90 | 92.50 | 824.00 |
| | Non-Hub 1,493.80 | | | |
| Variable Operating Costs (\$ Per Hour) | Hub 1,764.00 | 239.00 | 154.00 | 1025.00 |
| | Non-Hub 1,644.00 | | | |
| Occupants Per Aircraft | Hub 75.1 | 6.9 | 3.2 | 5.6 |
| | Non-Hub 19.7 | | | |
| Passengers Per Aircraft | Hub 61.4 | 5.1 | 3.2 | 5.6 |
| | Non-Hub 16.1 | | | |

Table E-1

Distribution of Air Carrier Aircraft Used in
Development of Critical Values

| <u>Air Carrier Type</u> | <u>Departures</u> | <u>Percent *</u> <u>Distribution</u> |
|----------------------------------|-------------------|---|
| Turbofan, 4-engine, Wide Body | 40757 | .0080 |
| Turbojet, 4-engine | 534 | .0001 |
| Turbofan, 4-engine, Regular Body | 203660 | .0399 |
| Turbofan, 3-engine, Wide Body | 255339 | .0500 |
| Turbofan, 3-engine, Regular Body | 1953905 | .3833 |
| Turbofan, 2-engine, Wide Body | 18967 | .0037 |
| Turbofan, 2-engine, Regular Body | 1842097 | .3613 |
| Turboprop | 614784 | .1206 |
| Piston | 168039 | .0330 |
| Total | 5098082 | 1.000 |

* Total does not exactly add to 1.000 due to independent rounding.

Source: Airport Activity Statistics of certificated Route Air
Carriers

Table E-2

Calculation of National Average Air Carrier Replacement/Restoration Costs and Variable Operations Costs ^{1/}

| Air Carrier Type | (A) Distribution By Type | (B) Replacement Cost ^{2/} | (C) (A) x (B) | (D) Cost Per Airborne Hr ^{3/} | (E) (A) x (D) \$ |
|------------------------|--------------------------------|--|------------------|--|-------------------------|
| Turbofan, 4 Eng., W.B. | .0080 | \$23,291,000 | \$ 186,300 | \$4884 | \$ 39.07 |
| Turbojet, 4 Eng. | .0001 | 1,819,000 | 200 | 2979 | .30 |
| Turbofan, 4 Eng., R.B. | .0399 | 4,500,000 | 179,600 | 2711 | 108.17 |
| Turbofan, 3 Eng., W.B. | .0500 | 23,353,000 | 1,170,000 | 3438 | 172.24 |
| Turbofan, 3 Eng., R.B. | .3833 | 4,501,000 | 1,725,200 | 2028 | 777.33 |
| Turbofan, 2 Eng., W.B. | .0037 | 22,740,000 | 84,100 | 2731 | 10.10 |
| Turbofan, 2 Eng., R.B. | .3613 | 5,849,000 | 2,113,200 | 1559 | 563.27 |
| Turboprop | .1206 | 1,443,000 | 174,000 | 729 | 87.92 |
| Piston | .0330 | 364,000 | 12,000 | 157 | 5.18 |
| | | | \$5,644,600 | | \$1763.58 |
| | | | Replacement Cost | | or \$1764 |
| | | | | | Variable Operating Cost |

Average Restoration Cost = $1/3 \times$ Average Replacement Cost
 = $1/3 \times \$5,644,600$
 = \$1,881,500 ^{4/}

1/ For Hub Airports

2/ Values taken from Reference E-1 p. ii, converted to 1981 dollars using method described in Reference E-1 p. 68. Producer Price Index for total transportation equipment for future year 1981 and base year 1980 are 254.05 and 207.0 respectively (12/68 = 100). The ratio of 254.05/207.0 is applied to each replacement value to obtain a 1981 value.

3/ Values taken from Reference E-1 p. iii, converted to 1981 dollars using method described in Reference E-1 p. 69. For fuel and oil: Ratio of 1981 to 1978 mean jet fuel type A costs per gallon (\$1.70/\$.79). Source: Reference E-8. For Maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977=100: 138.9/108.1.

4/ Rounded to Hundreds of Dollars.

Table E-3

Calculation of National Average Air Carrier Replacement/Restoration Costs and Variable Operations Costs 1/

| Air Carrier Type | (A) Distribution BY Type | (B) Replacement Cost <u>2/</u> | (C) (A) x (B) | (D) Cost Per Airborne Hr <u>3/</u> | (E) (A) x (D) |
|------------------------|--------------------------------|--------------------------------------|------------------|--|------------------|
| Turbojet, 4 Eng. | .0001 | \$1,819,000 | \$ 200 | 2979 | .30 |
| Turbofan, 4 Eng., R.B. | .0426 | 4,500,000 | 191,700 | 2711 | 115.49 |
| Turbofan, 3 Eng., R.B. | .4085 | 4,501,000 | 1,838,700 | 2028 | 828.44 |
| Turbofan, 2 Eng., R.B. | .3851 | 5,849,000 | 2,252,500 | 1559 | 600.37 |
| Turboprop, 2 Eng. | .1285 | 1,443,000 | 185,400 | 729 | 93.68 |
| Piston 2 E. | .0351 | 364,000 | 12,800 | 157 | 5.51 |
| | | | \$4,481,300 | \$1643.79 | |
| | | | Replacement Cost | or | |
| | | | | \$1644 | |
| | | | | Variable Operating | |
| | | | | Cost | |

Average Restoration Cost = $1/3 \times$ Average Replacement Cost
 = $1/3 \times \$4,481,300$
 = \$1,493,800 4/

1/ For Non-Hub Airports

2/ Same as Footnote 2 for Hub

3/ Same as Footnote 3 for Hub

4/ Rounded to Hundreds of Dollars

Table E-4

Calculation of Number of Passengers
In Air Carriers

At Hub Airports:

Total No. Passengers Enplanements = 272,737,327 = 61.4
Completed Departures 4460248 passengers

At Non-Hub Airports:

Total No. Passengers Enplanements = 8,639,252 = 16.1
Completed Departures 536607 passengers

Source: Airport Activity Statistics of Certificated Route Air
 Carriers. December 1980.

Table E-5

Calculation of Number of Occupants in Air Carriers (Hub Airports)

| <u>Air Carrier Type</u> | (A) | (B) | (C) |
|-------------------------|---------------------------------------|--|---------------------|
| | <u>Distribution</u> <u>By Type</u> | <u>Number of</u> <u>Occupants</u> ^{1/} | <u>(A) x (B)</u> |
| Turbofan, 4 Eng., W.B. | .0080 | 251.7 | 2.01 |
| Turbojet, 4 Eng. | .0001 | 100.3 | .01 |
| Turbofan, 4 Eng., R.B. | .0399 | 107.7 | 4.30 |
| Turbofan, 3 Eng., W.B. | .0500 | 169.5 | 8.49 |
| Turbofan, 3 Eng., R.B. | .3833 | 84.4 | 32.35 |
| Turbofan, 2 Eng., W.B. | .0037 | 148.3 | .55 |
| Turbofan, 2 Eng., R.B. | .3613 | 66.6 | 24.06 |
| Turboprop | .1206 | 26.5 | 3.20 |
| Piston | .0300 | 4.2 | .14 |
| | | | 75.11 ^{2/} |
| | | | Occupants |

Weighted Average

^{1/} Reference E-8^{2/} Rounded to nearest hundredthDerivation of Number of Occupants In Air Carriers
(Non-Hub Airports)

Average number of occupants is estimated based on the proportional relationship of passengers on air carrier aircraft at non-hub and hub airports taken from Table E-4.

$$\frac{16.1}{61.4} = .2622, \quad 75.11 \times .2622 = 19.69$$

Average number of occupants in air carriers at non-hub airports is estimated to be:

19.69 Occupants

Table E-6

Calculation of Air Taxi Replacement/Restoration Costs

| <u>Aircraft Type</u> | (A) Distribution | (B) Replacement | (C) |
|----------------------|---------------------|--------------------|------------------|
| | <u>By Type 1/</u> | <u>Cost 2/</u> | <u>(A) x (B)</u> |
| Jet | 0.0604 | 1,478,000 | \$ 89,271 |
| Turboprop | 0.1883 | 632,000 | 119,006 |
| Multi-Engine Piston | 0.5767 | 116,000 | 66,897 |
| Single-Engine Piston | 0.1690 | 35,000 | 5,915 |
| Rotorcraft | 0.0055 | 130,000 | 715 |
| | | | <u>\$281,804</u> |
| | | | Replacement Cost |

Average Restoration Cost = $1/3 \times$ average replacement cost

= $1/3 \times \$281,800$

= \$93,900

1/References E-3, E-4

2/Reference E-1

Table E-7

Variable Operating Costs of Air Taxi 1/

| | (A) Crew | (B) Fuel | (C) Mainten. | (D) Total | (E) Distribution | | (D) x (E) |
|--|-------------|-------------|-----------------|--------------|---------------------|--|-----------|
| | | | | | By Type | | |
| Single Eng. Piston 1-3 <u>2/</u> | \$25.70 | 20.64 | 8.02 | 54.36 | .0002 | | 0.01 |
| Single Eng. Piston 4+ <u>3/</u> | 25.70 | 25.80 | 12.25 | 63.75 | .1688 | | 10.76 |
| Twin-Eng. Piston <12,500 lbs. <u>4/</u> | 42.40 | 52.45 | 52.71 | 147.56 | .5767 | | 85.10 |
| Twin-Eng. Turbo. <12,500 lbs. <u>5/</u> | 187.60 | 117.52 | 99.39 | 404.51 | .1851 | | 74.87 |
| Twin-Eng. Turbo. ≥12,500 lbs. <u>6/</u> | 187.60 | 426.63 | 231.67 | 845.90 | .0032 | | 2.71 |
| Twin-Eng. <u>TJ/F</u> <20,000 <u>7/</u> | 307.09 | 542.41 | 208.51 | 1058.01 | .0570 | | 60.31 |
| Twin-Eng. <u>TJ/F</u> ≥20,000 <u>8/</u> | 307.09 | 762.02 | 261.81 | 1330.92 | .0034 | | 4.53 |
| *Rotary Piston <u>9/</u> | 25.70 | 28.67 | 32.37 | 86.74 | - | | - |
| Rotary Turbine <u>10/</u> | 51.40 | 48.29 | 71.68 | 171.37 | .0055 | | .94 |

Weighted Avg.

\$239.23 or
\$239.00 Variable
Operating Costs

*IFR activity very close to zero

Footnotes on following page.

Footnotes to Table E-7

- 1/ All values are from reference E-1, and have been converted to 1981 dollars using the methodology described on pages 67-69.
- 2/ For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source: Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100. 137.5/108.4 was applied to base year values.
- 3/ For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source: Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100. 137.5/108.4 was applied to base year values.
- 4/ For fuel and oil: Ratio of 1981 to 1978 mean 100/130 aviation gas costs per gallon (\$1.90/\$.91) was applied to base year values. Source: Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source: Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100. 137.5/108.4 was applied to base year values.
- 5/ For fuel and oil: Ratio of 1981 to 1978 mean jet type A fuel costs per gallon (\$1.70/\$.79). Source: Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source: Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100. 137.5/108.4 was applied to base year values.
- 6/ For fuel and oil: Ratio of 1981 to 1978 mean jet type A fuel costs per gallon (\$1.70/\$.79). Source: Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source: Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100. 137.5/108.4 was applied to base year values.
- 7/ For fuel and oil: Ratio of 1981 to 1978 mean job type A fuel costs per gallon (\$1.70/\$.79). Source: Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source: Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100. 137.5/108.4 was applied to base year values.

Footnotes to Table E-7 (Continued)

8/ For fuel and oil: Ratio of 1981 to 1978 mean jet type A fuel costs per gallon (\$1.70/\$.79). Source: Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source: Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100. 137.5/108.4 was applied to base year values.

9/ Same as footnote 5 above.

10/ Same as footnote 5 above.

Table E-8

Calculation of Average Number of Occupants and
Passengers in Air Taxis (Including Commuters)

| <u>Aircraft Type</u> | (A) Distribution By Type 1/ | (B) Number of Occupants 2/ | (C) (A) x (B) | (D) Number of Passengers 3/ | (E) (A) x (D) |
|----------------------|-----------------------------------|----------------------------------|----------------------|-----------------------------------|------------------|
| Jet | .0604 | 4.3 | .2598 | 2.3 | .1389 |
| Turboprop | .1883 | 9.3 | 1.7512 | 7.3 | 1.3746 |
| Multi-eng. Piston | .5767 | 7.4 | 4.2676 | 5.4 | 3.1142 |
| Single-Eng. Piston | .1690 | 3.1 | .5240 | 2.1 | .3549 |
| Rotorcraft | .0055 | 2.4 | .0132 | 1.4 | .0077 |
| | | | <u>6.9 Occupants</u> | | <u>5.1</u> |
| | | | | | Passengers |

Weighted Avg.

1/ From references E-3, E-4

2/ From reference E-8

3/ From reference E-8

Table E-9

Calculation of General Aviation Replacement/Restoration Costs

| | (A) | (B) | (C) |
|------------------------------|-------------------|----------------|------------------|
| | Distribution | | |
| Replacement Aircraft Type | By Type <u>1/</u> | Cost <u>2/</u> | (A) x (B) |
| Jet | .0834 | 1,812,000 | \$151,121 |
| Turboprop | .1057 | 708,000 | 74,836 |
| Multi-Engine Piston | .3112 | 116,000 | 36,099 |
| Single-Engine Piston | .4988 | 31,000 | 15,463 |
| Rotorcraft | .0008 | 84,000 | 67 |
| | | | <u>\$277,586</u> |
| | | | Replacement Cost |

Average Restoration Cost = $1/3 \times$ average replacement cost
 = $1/3 \times \$277,600$
 = \$92,500

1/ References E-3, E-4.

2/ Reference E-1

Table E-10

Variable Operating Costs of General Aviation Aircraft ^{1/}

| | (A) Fuel/ Oil | (B) Maintenance | (C) Total | (D) Distribution By Type | (C) x (D) |
|--|---------------------|--------------------|--------------|--------------------------------|-----------|
| Single-Eng. Piston 1-3 ^{2/} | \$20.64 | 8.02 | 28.66 | .0094 | \$0.27 |
| Single-Eng. Piston 4+ ^{3/} | 25.80 | 12.25 | 38.05 | .4894 | 18.62 |
| Twin-Eng. Piston <12,500 lbs. ^{4/} | 53.45 | 52.71 | 105.16 | .3112 | 32.73 |
| Twin-Eng. Turbo. <12,500 lbs. ^{5/} | 117.52 | 99.39 | 216.91 | .0935 | 20.28 |
| Twin-Eng. Turbo. ≥12,500 lbs. ^{6/} | 426.63 | 231.67 | 658.30 | .0122 | 8.03 |
| Twin-Eng. T _J /F <20,000 ^{7/} | 542.41 | 208.51 | 750.92 | .0460 | 34.54 |
| Twin-Eng. T _J /F ≥20,000 ^{8/} | 762.01 | 261.81 | 1023.83 | .0322 | 32.97 |
| Multi-Eng. T _J /F ^{9/} | 835.54 | 592.62 | 1428.16 | .0052 | 7.43 |
| *Rotary Piston ^{10/} | 28.67 | 32.37 | 61.04 | - | - |
| Rotary Turbine ^{11/} | 48.29 | 71.68 | 119.97 | .0008 | .10 |

Weighted Avg.

\$154.97 or
\$154 Variable
Operating Costs

*IFR Activity Very Close to Zero

Footnotes to Table E-10

- 1/ All values are from reference E-1, and have been converted to 1981 dollars using the methodology described on pages 67-69.
- 2/ For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/108.4 was applied to base year values.
- 3/ For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/108.4 was applied to base year values.
- 4/ For fuel and oil: Ratio of 1981 to 1978 mean 100/130 aviation gas costs per gallon (\$1.90/\$.91) was applied to base year values. Source Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/108.4 was applied to base year values.
- 5/ For fuel and oil: Ratio of 1981 to 1978 mean jet type A fuel costs per gallon (\$1.70/\$.79). Source Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/108.4 was applied to base year values.
- 6/ For fuel and oil: Ratio of 1981 to 1978 mean jet type A fuel costs per gallon (\$1.70/\$.79). Source Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/108.4 was applied to base year values.
- 7/ For fuel and oil: Ratio of 1981 to 1978 mean job type A fuel costs per gallon (\$1.70/\$.79). Source Reference E-7. For crew and maintenance: For fuel and oil: Ratio of 1981 to 1978 mean 80/87 aviation gas costs per gallon (\$1.85/\$.89) was applied to base year values. Source Reference E-7. For crew and maintenance: Ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/108.4 was applied to base year values.

AD-A135 606

ESTABLISHMENT AND DISCONTINUANCE CRITERIA FOR PRECISION
LANDING SYSTEMS(U) FEDERAL AVIATION ADMINISTRATION
WASHINGTON DC OFFICE OF AVIATION POLICY AND PLANS

UNCLASSIFIED

J A HAWKINS SEP 83 FAA-APD-83-10

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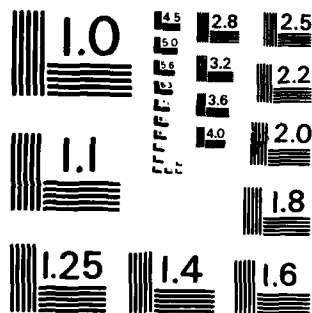
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DATE

FILED

1-84

OTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Footnotes to Table E-10 (Continued)

8/ Same as footnote 5 above.

9/ Same as footnote 5 above.

10/ Same as footnote 5 above.

11/ Same as footnote 5 above.

Calculating Numbers of Occupants and Passengers for
Other Aircraft Classes

The calculation of the average number of occupants for itinerant general aviation and military are shown in Tables E-11 and E-14, respectively. Since no crew salaries or wages are included in the variable operating costs for these aircraft, the number of passengers used in calculating the averted flight disruption benefits is equal to the number of occupants. The calculations for general aviation aircraft involved an additional step. Before proceeding with the usual weighted average computation it was first necessary to identify the portion of an aircraft's total flying hours that were itinerant and which were local. Local flying time is not relevant to this analysis. Since pilots flying locally (within 20 miles of departure airport) can elect not to fly at all if weather is too poor thereby limiting their need to use a precision landing aid.

Table E-11

Calculation of Average Number of Occupants for General Aviation

| <u>Aircraft Type</u> | (A) Distribution <u>By Type</u> ^{1/} | (B) Number of <u>Occupants</u> ^{2/} | (C) <u>(A) x (B)</u> |
|----------------------|---|--|-------------------------|
| Jet | .0834 | 4.1 | .3419 |
| Turboprop | .1057 | 5.6 | .5919 |
| Multi-Engine Piston | .3112 | 3.6 | 1.1203 |
| Single-Engine Piston | .4988 | 2.2 | 1.0974 |
| Rotorcraft | .0008 | 2.4 | .0019 |
| | | | 3.2 |
| | | | Occupants/Passengers |

^{1/} Derived using information from references E-3, E-4

^{2/} Reference E-8

Table E-12

Calculation of Military Aircraft Replacement/Restoration Costs

| | (A) | (B) | (C) |
|----------------------|---------------------|---------------------------|--------------------|
| <u>Aircraft Type</u> | <u>Distribution</u> | <u>Replacement</u> | |
| | <u>By Type</u> | <u>Cost ^{1/}</u> | <u>(A) x (B)</u> |
| Jet | .7586 | 2,440,000 | 1,850,984 |
| Turboprop | .1631 | 3,784,000 | 620,359 |
| Piston | .0781 | 121,000 | 9,450 |
| Rotorcraft | .0018 | 466,000 | 839 |
| | | | <u>\$2,471,632</u> |
| | | | Replacement Cost |

Average Restoration Cost = $1/3 \times$ average replacement cost
 $= 1/3 \times \$2,472,000$
 $= \$823,000$

^{1/} Reference E-1

Table E-13

Variable Operating Costs of Military Aircraft ^{1/}

| | (A) Fuel/ Oil | (B) Maintenance | (C) Total | (D) Relative Importance | (C) x (D) |
|----------------------------------|---------------------|--------------------|--------------|-------------------------------|--------------------------|
| <u>Fixed Wing</u> | | | | | |
| Multi-Eng. TU/F ^{2/} | \$2006.00 | 362.00 | 2368.00 | .0933 | 220.93 |
| Twin-Eng. TU/F ^{3/} | 1149.00 | 185.00 | 1334.00 | .4757 | 567.88 |
| Single-Eng. TU/F ^{4/} | 738.00 | 145.00 | 883.00 | .1896 | 167.42 |
| Turboprop ^{5/} | 217.00 | 155.00 | 372.00 | .1613 | 60.04 |
| Piston ^{6/} | 52.00 | 58.00 | 110.00 | .0781 | 8.59 |
| <u>Rotary Wing</u> ^{7/} | 57.00 | 72.00 | 119.00 | .0018 | .21 |
| Weighted Avg. | | | | | \$1025.07 or \$1025 |
| | | | | | Variable Operating Costs |

^{1/} All values are from reference E-1, and have been converted to 1981 dollars using the methodology described on pages 67-69.

^{2/} For Fuel and oil: Ratio of 1981 to 1978 mean jet type A fuel costs per gallon (\$1.70/\$.79) was applied to base year values. Source Reference E-7. For maintenance ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/1084 - was applied to base year values.

^{3/} For Fuel and oil: Ratio of 1981 to 1978 mean jet type A fuel costs per gallon (\$1.70/\$.79) was applied to base year values. Source Reference E-7. For maintenance ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/1084 - was applied to base year values.

^{4/} Same as footnote 2.

^{5/} Same as footnote 2.

^{6/} For fuel and oil: Ratio of 1981 to 1978 mean 100/130 aviation gas costs per gallon (\$1.90/\$.91) was applied to base year values. Source Reference E-7. For maintenance: For Fuel and oil: Ratio of 1981 to 1978 mean jet type A fuel costs per gallon (\$1.70/\$.79) was applied to base year values. Source Reference E-7. For maintenance ratio of 1981 to 1978 BLS indices of adjusted hourly earnings where 1977 = 100-137.5/1084 - was applied to base year values.

^{7/} Same as footnote 2.

Table E-14

Calculation of Average Number of Occupants for Military Aviation

| <u>Aircraft Type</u> | (A) Distribution By Type | (B) Number of Occupants <u>1/</u> | (C) <u>(A) x (B)</u> |
|----------------------|--------------------------------|---|-------------------------|
| Jet | .7586 | 6.0 | 4.5516 |
| Turboprop | .1613 | 5.0 | .8065 |
| Piston | .0781 | 3.0 | .2343 |
| Rotorcraft | .0018 | 2.0 | <u>.0036</u> |
| | | | 5.6 |
| | | | Occupants/Passengers |

1/ Reference E-8

Bibliography

- E-1 Economic Values for Evaluation of Federal Aviation
Administration Investment and Regulatory Programs, Report Number
FAA-APO-81-3 September 1981.
- E-2 Air Traffic Activity Fiscal Year 1980, FAA Office of Management
Systems, September 1980.
- E-3 General Aviation Activity and Avionics Survey, Report Number
FAA-MS-81-1, FAA Office of Management Systems, January 1981.
- E-4 General Aviation Pilot and Aircraft Activity Survey, Report
Number FAA-MS-79-7, December 1979.
- E-5 FAA Aviation Forecasts, Fiscal Years 1981-1992, September 1980.
- E-6 Economic Report of the President, 1981.
- E-7 FAA Office of Environment and Energy, Energy Division (AEE-200).
- E-8 Investment Criteria for Airport Surveillance Radar
(ASR/ATCRBS/ARTS) Draft Report, Report Number FAA-APO-81-13,
November 1981.
- E-9 Airway Planning Standard Number One, Terminal Air Navigation
Facilities and Air Traffic Control Services, FAA Order 7031.2B.
- E-10 Economic Analysis of Investment and Regulatory Division--A
Guide, Report Number FAA-APO-82-1, January 1982.
- E-11 Airport Activity Statistics of Certificated Route Air Carriers,
12 months Ending December 31, 1980, CAB/DOT.

APPENDIX F

SAFETY BENEFITS

National Transportation Safety Board (NTSB) computer records of all civil aviation accidents for the period January 1971 through December 1979 form the basis upon which the benefits of preventable landing accidents were developed. To select accidents relevant to the analysis, all landing accidents in 1979 were printed out. In some cases, the handwritten accident files from which the computer data were coded were examined. After coding patterns and limitations were examined, the selection criteria were refined. Accidents were collected in two categories, those which occurred during or immediately after a non-precision approach, and for a precision approach. The following selection logic was used:

- o aircraft "incidents" were deleted, and aircraft "accidents" retained;
- o accidents where the phase of flight was other than "landing" were deleted. Within the landing phase, only "final approach from final fix - IFR," "level off/touchdown," "rollout," and "missed approach - IFR" were selected;
- o accidents which were forced landings were deleted, unless the forced landing code was "precautionary landing on airport;"
- o accidents were not selected unless the weather was coded as "IFR" or "below minimums;"
- o if the "type of instrument approach" was coded as a precision approach -- straight in ILS, MLS or PAR,--the accident was counted as a precision approach accident;
- o if the "type of instrument approach" was coded as a non-precision approach -- a circling precision approach, or an ADF, VOR, VOR/DME, or localizer -- the accident was counted as a non-precision approach accident;
- o if the type of IFR approach was not coded, but the type flight plan was IFR, then the approach was counted as a non-precision approach accident;

This examination made it possible to identify the number of landing accidents that occurred, and the associated fatalities, injuries (serious and minor), and degree of aircraft damage (substantial damage or destroyed). The cost of an accident was evaluated based on the number of deaths, injuries, and extent of aircraft damage.

FAA statistics (Reference F-4) on the number of instrument approaches made during the same period were examined for each airport to derive an estimate of the number of precision versus nonprecision approaches that

constituted the total. The assumptions were: (1) if the airport had no ILS's, then all instrument approaches reported for that airport were nonprecision; (2) if one ILS was present, seventy percent of the instrument approaches were flown as precision approaches; (3) if two or more ILS's were present, ninety percent of the instrument approaches were precision approaches; (4) the avionics equipage rates were 100 percent for air carrier, air taxi, and military, and 98 percent for General Aviation Aircraft. The 98% equipage rate is based on (Reference F-5) data, which showed that of aircraft reporting IFR hours flown, 98% had glide slope equipment on board.

Using the information obtained from the NTSB file and the FAA statistics on instrument approaches, it was possible to develop a landing accident history (Table F-1, on page F-6).

Safety benefits of precision landing aids are estimated by comparing the incidence and resulting costs of non-precision approach accidents with the same for precision approach accidents to estimate a differential cost per approach. This differential is then multiplied by the number of annual precision instrument approaches to complete the safety benefit for a given year. This is done for all aircraft classes. As with averted flight disruption benefits, safety benefits must be computed using current and forecast instrument approach activity for each year over a 15 year time stream. Accident costs are measured by the frequency and resulting costs of fatalities, injuries (serious and minor) and aircraft damage. The total safety benefit to an airport obtained by having precision approach capability is estimated by the following relationships. A brief summary explaining their meaning immediately follows the list of notational definitions.

(1) Reduced fatality benefit:

$$\sum_{AC, AT, GA, MIL} (R_{np} \times FF_{np} \times O_{cc}) - (R_p \times FF_p \times O_{cc}) \times PIA \times CF = BRF$$

(2) Reduced minor injuries:

$$\sum_{AC, AT, GA, MIL} (R_{np} \times FMI_{np} \times O_{cc}) - (R_p \times FMI_p \times O_{cc}) \times PIA \times CMI = BRMI$$

(3) Reduced serious injuries:

$$\sum_{AC, AT, GA, MIL} (R_{np} \times FSI_{np} \times O_{cc}) - (R_p \times FSI_p \times O_{cc}) \times PIA \times CSI = BRSI$$

(4) Reduced destroyed aircraft benefit:

$$\sum_{AC, AT, GA, MIL} (R_{np} \times DR_{np}) - (R_p \times DR_p) \times PIA \times CRPL = BRD$$

(5) Reduced damaged aircraft:

$$\sum_{AC, AT, GA, MIL} (R_{np} \times SR_{np}) - (R_p \times SR_p) \times PIA \times CREST = BRS$$

$$\text{Total Safety Benefit} = (1) + (2) + (3) + (4) + (5)$$

where:

- R_{np} = accident rate for non-precision approaches
- R_p = accident rate for precision approaches
- FF_{np} = fraction of occupants expected to be killed in an accident during a non-precision approach
- FF_p = fraction of occupants expected to be killed in an accident during a precision approach
- FMI_{np} = fraction of occupants expected to suffer minor injuries in an accident during non-precision approach
- FMI_p = fraction of occupants expected to suffer minor injuries in an accident during a precision approach
- FSI_{np} = fraction of occupants expected to suffer serious injuries in an accident during a non-precision approach
- FSI_p = fraction of occupants expected to suffer serious injuries in an accident during a precision approach
- DR_{np} = percentage of the number of aircraft involved in non-precision approach accidents that are expected to be destroyed
- DR_p = percentage of the number of aircraft involved in precision approach accidents that are expected to be destroyed
- SR_{np} = percentage of the number of aircraft involved in non-precision approach accidents that are expected to be substantially damaged
- SR_p = percentage of the number of aircraft involved in precision approach accidents that are expected to be substantially damaged.
- O_{oc} = average number of occupants in all aircraft of an aircraft class
- PIA = precision instrument approaches ($PIA = IA \times \text{Avionics equipage rate} \times \% \text{ of runway utilization}$)

| | | |
|-------|---|--|
| CF | = | cost of a fatality in 1981 dollars |
| CMI | = | cost of a minor injury in 1981 dollars |
| CSI | = | cost of a serious injury in 1981 dollars |
| CRPL | = | aircraft replacement costs (weighted average based on aircraft mix at specific site) |
| CREST | = | aircraft restoration costs (weighted average based on aircraft mix at specific site) |
| BRF | = | benefit of reducing the number of expected fatalities |
| BRMI | = | benefit of reducing the number of expected minor injuries |
| BRSI | = | benefit of reducing the number of expected serious injuries |
| BRD | = | benefit from reducing the number of destroyed aircraft |
| BRS | = | benefit from reducing the number of substantially damaged aircraft |

A literal translation of each equation is in order. For each user class (i.e., air carrier, general aviation, air taxi, military):

Equation (1) says that the frequency of non-precision approach weather-related landing accidents (R_{np}), times the expected number of fatalities per accident ($FF_{np} \times OCC$), minus the frequency of precision approach weather-related landing accidents (R_p) times the expected number of fatalities per accident ($FF_p \times OCC$) is the reduction in the expected number of accident-related fatalities that results by having precision approach capability. This amount is then multiplied by the number of precision instrument approaches (PIA) that would be possible on the specific runway, and by the monetary value of life or fatality cost (CF). The result is an estimate of the benefit of reducing the number of weather-related landing accident fatalities at a runway when a precision approach aid is installed (BRF).

Equations (2) and (3) translate exactly as equation (1) except that in equation (2), "minor injuries" and the appropriate terms should be substituted in place of "fatalities" and the fatality terms, and in equation (3) "serious injuries" and the appropriate terms should be substituted in place of "fatalities" and the fatality terms.

Equation (4) says that the frequency of non-precision approach weather-related landing accidents (R_{np}) times the probability that the aircraft is destroyed (DR_{np}) minus the frequency of precision approach weather-related landing accidents (R_p) times the probability that the aircraft is destroyed (DR_p) is the reduction in the expected number of destroyed aircraft that results by having precision approach capability. This amount is then multiplied by the number of precision instrument approaches (PIA) that would be possible on the specific runway, and by the average cost of replacing

the aircraft (CRPL = f (aircraft mix at airport in question)). The result is an estimate of the benefit of reducing the expected number of destroyed aircraft suffered during weather-related landing accidents by installing a precision approach aid (BRD).

Equation (5) translates exactly as equation (4) except that in equation (5) "substantially damaged" and the appropriate terms should be substituted for "destroyed" and the related terms.

The total safety benefit of having precision-approach capability, then, is the sum of:

- (1) the benefit derived from reducing the number of fatalities (BRF)
- (2) the benefit derived from reducing the number of minor injuries (BMI)
- (3) the benefit derived from reducing the number of serious injuries (BSI)
- (4) the benefit derived from reducing the number of aircraft destroyed (BRD)
- (5) the benefit derived from reducing the number of aircraft that are substantially damaged (BRS)

This sum is found for all user classes and combined for a grand total safety benefit.

Realizing that regional offices will not always be able to provide site specific information regarding aircraft mix, average number of occupants, etc., estimates of safety benefits based on national averages have been derived and are presented in this report to be used when site specific data are not available. The following table summarizes the safety benefit estimates per precision instrument approach for each user class.

| <u>User Category</u> | <u>Safety Benefit of Precision Approach Capability Per Precision Approach</u> |
|----------------------|---|
| Air Carrier | |
| Hub | \$ 54 |
| Non Hub | 32 |
| Air Taxi | 180 |
| General Aviation | 35 |
| *Military | 132 |

*Estimate based on General Aviation Experience. Insufficient military data do not permit independent evaluation of military accident history.

TABLE F-1 LANDING ACCIDENT HISTORY 1971-1979

| <u>Precision</u> | (1) <u>Approaches</u> | (2) <u>Accidents</u> | (3) <u>OCC</u> | (4) <u>Fatalities</u> | (5) <u>Ser. Injuries</u> | (6) <u>Minor Injuries</u> | (7) <u>Destroyed</u> | (8) <u>Sub Damage</u> |
|----------------------|--------------------------|-------------------------|-------------------|--------------------------|-----------------------------|------------------------------|-------------------------|--------------------------|
| Air Carrier | 6,139,348 | 19 | 958 | 340 | 60 | 80 | 9 | 10 |
| Air Taxi | 1,279,359 | 27 | 51 | 20 | 7 | 8 | 16 | 11 |
| General Aviation | 4,285,558 | 112 | 352 | 197 | 58 | 45 | 79 | 33 |
| Military* | 671,780 | * | * | * | * | * | * | * |
| <u>Non Precision</u> | | | | | | | | |
| Air Carrier | 1,169,400 | 18 | 1043 | 101 | 91 | 65 | 5 | 13 |
| Air Taxi | 473,188 | 69 | 240 | 76 | 28 | 32 | 28 | 41 |
| General Aviation | 2,626,632 | 243 | 746 | 222 | 60 | 66 | 103 | 140 |
| Military | 429,498 | * | * | * | * | * | * | * |

TABLE F-1 (Continued)

| Precision | Accident Rates (10 ⁻⁶) (2 - 1) | Fraction of | | | Proportion of Aircraft Des- troyed (7 - 2) | Proportion of Aircraft Damaged (8 - 2) |
|------------------|---|-----------------------------|-----------------------------------|---|--|--|
| | | Occupants Killed (4 - 3) | Occupants Ser. Inj. (5 - 3) | Fraction of Occupants M/I (6 - 3) | | |
| Air Carrier | 3.1 | .3549 | .0626 | .0835 | .4737 | .5263 |
| Air Taxi | 21.1 | .3922 | .1373 | .1569 | .5926 | .4074 |
| General Aviation | 26.1 | .5597 | .1648 | .1278 | .7054 | .2946 |
| Military* | 26.1 | .5597 | .1648 | .1278 | .7054 | .2946 |

| Non Precision | Accident Rates (10 ⁻⁶) (2 - 1) | Fraction of | | Proportion of Aircraft Des- troyed (7 - 2) | Proportion of Aircraft Damaged (8 - 2) | |
|------------------|---|-----------------------------|-----------------------------------|--|--|-------|
| | | Occupants Killed (4 - 3) | Occupants Ser. Inj. (5 - 3) | | | |
| Air Carrier | 15.3 | .0968 | .0872 | .0623 | .2778 | .7222 |
| Air Taxi | 145.8 | .3167 | .1167 | .1334 | .4058 | .5942 |
| General Aviation | 92.5 | .2976 | .0804 | .0885 | .4239 | .5761 |
| Military* | 92.5 | .2976 | .0804 | .0885 | .4239 | .5761 |

*Military Accident Information was not available in usable format. With the exception of the number of approaches, all values for military have been estimated based on the General Aviation Experience.

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Bibliography

- F-1 Annual Review of Aircraft Accident Data, Civil Aviation, National Transportation Safety Board, various annual editions.
- F-2 Establishment Criteria for Category I ILS, FAA-ASP-75-1, December 1975
- F-3 NTSB Data File, 1971-1979, summary extract prepared by APO-100.
- F-4 Terminal Area Forecasts, Fiscal Years 1976-1981, Extract Prepared by APO-100.
- F-5 General Aviation Activity and Avionics Survey, 1979, extract prepared by APO-100.

APPENDIX G

ILS DECOMMISSIONING CRITERIA

The decision to decommission an ILS depends in part on whether turbojet operations are conducted on the runway and, if not, whether the benefits derived from its continued operation exceed the resulting operations and maintenance costs. That is, in the absence of turbojet operations, annual instrument approach (AIA) criteria will apply.

DEVELOPMENT OF DISCONTINUANCE CRITERIA

Annual O&M and fifteen year discounted O&M costs are summarized for an ILS system in Figure G-1.

Figure G-1

ILS Annual and 15 Yr. Discounted O&M Costs (1981 Dollars)

| <u>ILS</u> | <u>MALSR</u> | <u>TOTAL</u> |
|-----------------------|---------------------------------------|--|
| \$57 | \$16 | \$73 |
| <u>Annual O&M</u> | <u>Cumulative Discount Factor</u> | <u>Discounted 15 Yr. Costs (000)</u> |
| \$73 | 7.976 | \$582 |

The number of AIA's needed in order to cover the O&M costs can be determined by user class for several levels of non-precision approach minima following a methodology similar to that used in the development of the Phase I criteria for MLS establishment (Chapter VI). The same equation is used (i.e., $(AX + BY)(NDF) = \dots$) except that the ILS O&M costs replace the MLS life cycle costs, giving $(AX + BY)(NDF) = \$582,000$.

The minimum number of annual instrument approaches that would justify continued operation of ILS equipment have been found using this method for each user class for specific non-precision approach minima. This information is presented in Table G-1.

Table G-1

ILS Discontinuance Minimum AIA Count For Stated Non-Precision Approach Minima

| <u>User Category</u> | 300 3/4 | 400 3/4 | 400-1 | 500-1 | 600-1 | 800-1 |
|----------------------|---------|---------|-------|-------|-------|-------|
| Air Carrier | | | | | | |
| Hub | 200 | 100 | 80 | 50 | 40 | 20 |
| Non Hub | 400 | 200 | 170 | 120 | 85 | 40 |
| Air Taxi | 225 | 200 | 190 | 170 | 150 | 110 |
| General Aviation | 1100 | 950 | 850 | 700 | 600 | 400 |
| Military | 500 | 400 | 375 | 325 | 275 | 200 |

To determine whether a runway is a candidate for ILS discontinuance:

1. Determine the least non-precision approach minima currently authorized for the largest aircraft using the runway in question.
2. Reference table G-1 to select the required minimum number of AIA's on the candidate runway for each user category.
3. Estimate the number of recorded AIA's on the candidate runway for each user category.
4. Enter recorded and required AIA's for the candidate runway as indicated below. The contributions of each category toward meeting the criteria are summed. A runway with a total ratio below 1.0 is a candidate for discontinuance.

User Category

| | | |
|------------------|---|--------|
| Air Carrier | $\frac{\text{Recorded AIA's}}{\text{Required AIA's}}$ | = x.xx |
| Air Taxi | $\frac{\text{Recorded AIA's}}{\text{Required AIA's}}$ | = x.xx |
| General Aviation | $\frac{\text{Recorded AIA's}}{\text{Required AIA's}}$ | = x.xx |
| Military | $\frac{\text{Recorded AIA's}}{\text{Required AIA's}}$ | = x.xx |
| Total Ratio | | x.xx |

5. The decommissioning of an ILS will be justified by a benefit/cost assessment as well as by a review of operational and environmental factors pertinent to the affected locality or localities.